Oceanus®

Volume 27, Number 1, Spring 1984

Industry and The Oceans

Oceanus®

The Magazine of Marine Science and Policy
Volume 27, Number 1, Spring 1984

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Published by Woods Hole Oceanographic Institution

ISSN 0029-8182/83 $2.00 + .05

Editorial correspondence: *Oceanus* magazine, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543. Telephone (617) 548-1400, ext. 2386.

Subscription correspondence: All subscriptions, single copy orders, and change-of-address information should be addressed to *Oceanus* Subscriber Service Center, P.O. Box 6419, Syracuse, New York 13217. Please make checks payable to Woods Hole Oceanographic Institution. Subscription rate: $20 for one year. Subscribers outside the U.S. add $3 *per year* handling charge; checks accompanying foreign orders must be payable in U.S. currency and drawn on a U.S. bank. Current copy price, $4.75; forty percent discount on current copy orders of five or more. When sending change of address, please include mailing label. Claims for missing numbers will not be honored later than 3 months after publication; foreign claims, 5 months. For information on back issues, see inside back cover.

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Oceanus (ISSN 0029-8182) is published quarterly by the Woods Hole Oceanographic Institution, 93 Water Street, Woods Hole, Massachusetts 02543. Second-class postage paid at Falmouth, Massachusetts, and additional mailing points.

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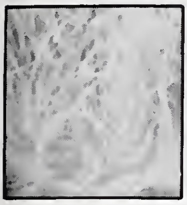

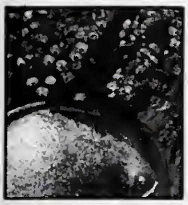

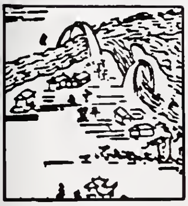

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The Cover: A male abalone releasing sperm in response to hydrogen peroxide. Photo by D. Morse. Back: Anton Dohrn being carried to shore, 1890. Naples Zoological Station (see page 60).

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comment

The theme of this issue of *Oceanus*—Industry and the Oceans—grew out of correspondence with Dr. Brinton M. Miller, a member of the American Society for Microbiology and an official of Merck, Sharp & Dohme Research Laboratories. Dr. Miller acquired an interest in *Oceanus* affairs when his daughter, Elizabeth, became one of my editorial colleagues. In an early letter to me, he suggested an issue on Industry's Use of the Oceans that would focus on "positive uses of the sea," as opposed to negative uses, such as "solid waste dump sites, dredging through clam beds, liquid and solvent dump sites and, yes, disturbing shore or bay land formations to make way for houses or bridges." Dr. Miller added that "our lay press and scientific journals often emphasize the latter at the expense of the former."

This issue is intended to partially rectify the imbalance that Dr. Miller feels exists. But as Editor I feel I would be remiss in not mentioning that some of the articles we have presented here *only* emphasize the positive and have made little mention of *anything* negative. Thus we are faced with another imbalance on the editorial seesaw. A couple of cases in point: the article on salmon ranching by William McNeil, general manager of Weyerhaeuser's Oregon Aqua Foods division, makes no mention of the bitter political battles that have been fought and are still being fought between the salmon ranchers and a united front of commercial fishermen and environmentalists (the issue is should this public resource remain public); scientific questions have also been raised about the possible genetic effects of additional millions of private hatchery fish on the naturally spawning salmon populations. Millions of potential dollars are at stake in a contest that revives memories of cattle range wars in the old West.

The article by Elizabeth Bauereis and John Kraeuter, employees of the Baltimore Gas & Electric Company, describing the partnership between a power plant and the raising of striped bass fingerlings, illustrates the potential that an industry has to aid a magnificent species that could face extinction in a relatively short period of time; however, the article makes no mention of the more than 20-year-old controversy that has surrounded the warm water discharges of the Maryland power company's plants into rivers and estuaries that feed Chesapeake Bay, a body of water that is ecologically endangered and the chief spawning grounds of East Coast striped bass. Still, we feel the reader will find the information presented in this issue very interesting in a "positive" sense. The great promise that exists for unsuspicious collaboration between marine industry and academic marine science is contained in these pages.

We are now embarked on the *Year of the Ocean* with its motto "celebration, education, and stewardship." Major events and festivals are planned for July 1 through 5 in ports and oceanographic laboratories across the country. Open houses will be held on ships of the National Oceanographic and Atmospheric Administration (NOAA), the Navy, and the Coast Guard.

Festivities began March 8, 1984, with a declaration by the President, resolutions in both houses of Congress, and open houses at NOAA facilities in 12 cities. The purpose of the *Year of the Ocean*—being spearheaded by NOAA—is to raise the consciousness of the American public about ocean affairs. On March 10, 1983, President Ronald Reagan proclaimed an Exclusive Economic Zone (EEZ) for the United States, extending Federal jurisdiction to 200 nautical miles offshore and claiming "sovereign rights" over living and nonliving resources in the area. This action raised many complex issues for those responsible for administering the added 6.1 million square miles of territory, chiefly regarding the United States' posture vis-á-vis the Law of the Sea Convention, which the President, after 14 years of U.S. negotiations, declined to become a party to because of its deep-sea mining provisions.

As we move into the *Year of the Ocean* there are many vital subjects to be addressed by scientists of the marine persuasion. Not the least of these are: the rising levels of CO_2 in the atmosphere (the ocean acts as a sink for CO_2), levels that may cause significant increases in temperature and sea levels within the near future; the rush to mine minerals in the form of polymetallic sulfides is on and almost every geophysical cruise these days turns up exciting new data for potential prospectors; and biological inquiry into the secrets of the recently discovered hot vents, investigations that should produce a wealth of interesting information on how life exists chemosynthetically as opposed to photosynthetically.

* * *

What does the title *Oceanus* stand for? This is a question that I'm often asked. In Greek mythology, Oceanus was one of the 12 Titans, the primeval deities overthrown by Zeus and the Olympians. Husband of Tethys and father of the river gods and sea nymphs, Oceanus was the personification of the circular stream that the Greeks believed flowed around the edge of the earth. The rising and falling of the sun and moon, they reasoned, was the source of all rivers.

With time, observations and reasoning have changed. We know now that the "circular stream" emcompasses 71 percent of the earth's surface. The modern Titan is Science. And though we know a lot about the oceans, they remain our planet's last frontier, still as foreboding and mysterious in many ways as the circular stream was for the Greeks.

Paul R. Ryan

The Industrial Potential of Marine Biotechnology

by

R. R. Colwell

It is an exciting time for marine biology—the explosive development of biotechnology and its handmaiden, "genetic engineering," has reached the marine sciences. Fascinating natural products are being discovered in marine sponges, algae, sea cucumbers, bacteria, and other organisms living in the sea.

The new technology of genetic engineering allows the excision of genetic material from the producing organism and transfer into bacteria, whereby the compounds, metabolites, or gene product can be produced by the bacteria in the laboratory. Thus, we can now envision entirely new "harvests" from the sea. The unusual chemistry of exotic marine plants and animals is within reach of industry, producible on a mass scale for the betterment of the health and well-being of mankind.

Without a great deal of fanfare, agriculture has incorporated biotechnology into crop production, with plant-tissue culture being employed for commercial production of ornamental plants and for crop improvement, especially in the case of nitrogen fixation, with attempts to manipulate the nitrogen fixation gene from bacteria into plants. In the case of plant breeding, genetic engineering—the application of fundamental knowledge of the molecular basis of biological processes to practical industrial and medical problems—involves genetic transformations through cell fusion and insertion or modification of genetic information via the cloning of DNA and its vectors.

Techniques are now available for manipulating organs, tissues, cells, or protoplasts in culture; for regenerating plants; and for testing the genetic basis of new or unusual traits. These methods, applied to plant breeding, have achieved good success in growing cells in tissue culture into mature plants, examples of which include asparagus, citrus fruits, pineapples, strawberries, and soybeans. Similar efforts, but at a far more rudimentary stage, are underway for seaweeds and marine plants.

Genetic engineering has not yet been applied on a large scale to the production of fish, molluscs, and crustaceans in natural environments and hatchery systems; however, a unique promise exists for aquaculture. *In vitro* manipulations, such as cloning, cell fusion, production of chimeras, and other recombinant DNA techniques, provide impetus for major advances in fish and shellfish genetics.

Clones of homozygous diploid zebra fish (*Brachydanio rerio*) have already been produced, and successful aquaculture of many species of invertebrate animals has been achieved. Since large populations of shellfish at the larval and intermediate stages can be manipulated and their genes cloned, the stage is set for the realization of genetic engineering's staggering potential for aquaculture.

The financial possibilities of genetic engineering have not been lost on the stock market. Investors have embraced (nearly smothered, in fact) new young companies with risk capital. Like mushrooms, these companies have sprung up in large numbers and in unexpected places. Without a doubt, gene manipulation can provide similar new opportunities to the marine sciences. Gene manipulation creates new combinations of heritable material by inserting nucleic acid molecules (the

basic genetic material of nearly all organisms) into a virus, bacterial plasmid, or other vector system— a transformation that incorporates into a host organism heritable material it does not naturally possess, but once inserted can recreate through natural propagation. Colloquially referred to as "genetic engineering," these methods can be readily applied to aquaculture of oysters and other molluscan species.

The most dramatic examples of the potential of biotechnological application for industry are the marine pharmaceuticals. In a 1977 conference, "Drugs and Food from the Sea: Myth or Reality," researchers described cardiotonic polypeptides from sea anemones, and adrenergic compounds from the sponge, *Verongia fistularis*, and potential anticancer agents from Caribbean gorgonians and soft corals. More recently, antiviral and antitumor depsipeptides from a Caribbean tunicate have been described. Extracts prepared from the Caribbean tunicate, an ascidian or sea squirt of the family *Didemnidae*, have been shown to inhibit growth of DNA and RNA viruses, as well as L1210 leukemic cells. These depsipeptides—termed didemnins after the name of the tunicate family, *Didemnidae*, from which they are isolated—are closely related, but vary in activity. Thus, the subphylum Tunicata or Urochordata (phylum Chordata) may be an abundant source of bioactive compounds of pharmaceutical interest.

A variety of compounds from the sea that act on the cardiovascular and central nervous systems also have been reported and this literature was recently (1981) reviewed by P. N. Kaul, who pointed out that drugs of high pharmacologic activity from nature, in fact, have been unsurpassed by synthetic compounds. For example, morphine, atropine, and digitalis glycosides were obtained from plants. Marine animals and plants have yielded cardiovascular-active substances, including histamine and N-methylated histamines of the sponge, *V. fistularis;* asystolic nucleosides from the sponge, *Dasychalina cyathina;* and the nucleoside, spongosine, isolated from *Cryptotethya crypta.*

Several marine organisms have provided useful drugs: liver oil from some fish provides an excellent source of vitamins A and D; insulin has been extracted from whales and tuna fish; and the red alga, *Digenia simplex*, has long been used as an anthelmintic.* Bacteriologists, for many years, have incorporated agar and alginic acids (from seaweeds) into laboratory media.

Marine toxins have fascinated biologists for decades. A toxin is a substance possessing a specific functional group arranged in the molecule(s), showing strong physiological activity, and having the potential to be applied as a drug or pharmacological reagent. If direct use as a drug is not feasible, because of potent or harmful side effects, a toxin often can serve as a model for synthesis or improvement of other drugs. Many attempts have been made to develop useful drugs from the sea by screening for anticarcinogenic, antibiotic, growth-promoting (or inhibiting), hemolytic, analgesic, antispasmodic, hypotensive, and hypertensive agents.

Two successes demonstrate the potential. Tetrodotoxin, the main action of which is paralysis of peripheral nerves, is a valuable pharmacological reagent because it specifically inhibits the sodium permeability of nerve membranes, and has allowed elucidation of the excitation mechanism. Obviously, applications of marine toxins are limited, to say the least, and it is mainly in the area of understanding functions that the toxins have an interest at the present time.

However, the second success worthy of mention is an insecticide developed from nereistoxin and widely marketed since 1966. Fishermen are familiar with the fact that flies die when they come into contact with the dead marine annelid, *Lumbrinereis* (*Lumbriconereis*) *brevicirra*, commonly used as bait. Nereis toxin was first isolated in 1934, and once its structure was determined, a new insecticide was developed from it. Cartap hydrochloride is one of the synthesized derivatives. It is active against the rice stem borer and other insect pests, and does not appear to be toxic to warm-blooded animals. Another positive attribute of this insecticide is that resistant strains of insects do not seem to develop readily.

Y. Hashimoto, for his book (1979), compiled the extensive literature summarizing information about marine organisms that cause food poisoning or possess the capacity to produce a toxic sting or bite or are poisonous, as in the case of the toxic marine flagellates such as *Gonyaulax* and *Gymnodinium* species. The vast array of marine animals and plants covered in this compendium includes flagellates, corals, jellyfish, sea anemones, nemertines, annelids, molluscs, enchinoderms, and other invertebrates, and fish.

Marine toxins show great promise not only as pharmacological reagents, but also as models for the development of new synthetic chemicals. Recently ciguatoxin, palytoxin, and halitoxin also have been investigated and provide interesting new information. Ciguatera is a human disease caused by the ingestion of any of a wide variety of coral reef fishes containing toxins they have accumulated via the marine food web (see *Oceanus*, Vol. 25, No. 2, p. 54). The principal toxin of ciguatera poisoning is a heat-stable, lipid-soluble compound named ciguatoxin, and the source of ciguatera toxin(s) is a photosynthetic, benthic dinoflagellate, *Gambierdiscus toxicus* (Adachi and Fukuyo). The term ciguatera was derived from a name used in the 18th century in the Spanish Antilles for intoxication caused by ingestion of the "Cigua" or turban shell *Cittarium* (*Livona* or *Turbo*) *pica*. Occurrence of ciguatera was recorded as early as the 1400s in the West Indies. The origin of the toxin is unknown, but it may be derived by the fish from ingestion of toxic tropical red-tide dinoflagellates such as *Pyrodinium bahamense.*

The primary action of ciguatoxin in victims appears to be an increase in permeability of the excitable membranes to sodium, causing

* A drug used to remove parasitic worms from their hosts.

depolarization. Application of gene cloning techniques has not been done, but this compound has potential for pharmaceutical applications.

Lophotoxin (LTx) is a lethal substance recently discovered in several species of sea whips of the genus *Lophogorgia*. It was originally discovered during a search for the mechanisms of chemical defense of marine organisms. Sea fans and whips of the phylum Cnidaria, order Gorgonaceae, found in tropical or subtropical waters, possess cytotoxic, ichthyotoxic, and antibacterial activity. Lophotoxin, after isolation and purification, was found to inhibit nerve-stimulated muscle contraction without affecting those contractions evoked by direct electrical stimulation of the muscle. Specifically, the data indicate that LTx blocks transmission at the site of the nicotinic receptor-channel complex. Epoxylactone and furanoaldehyde groups have been associated with the potent biological properties of lophotoxin. The novel chemical structure of LTx and its ability to induce neuromuscular blocking of an unusual type indicates that LTx may represent a new class of neuromuscular blocking agent with unique pharmacological properties.

Palytoxin is an extremely poisonous, water-soluble substance from marine cnidarians belonging to the genus *Palythoa*. It is very likely the most toxic nonprotein known, similar to ricin in potency (a polypeptide toxin found in castor beans). Although not quite as deadly as the toxin of *Clostridium botulinum*, it exerts a lethal effect on laboratory animals when administered intravenously in low concentrations. Interestingly, palytoxin was used by natives on Maui to tip their weapons as a defensive advantage against invaders from the island of Hawaii (see *Oceanus*, Vol. 25, No. 2, p. 54).

Palytoxin influences calcium- and potassium-ion transport in nerves and the heart. Animals undergo paralysis and heart failure.

The fascinating aspect of palytoxin is that it is synthesized by a marine *Vibrio* species growing symbiotically with the cnidarians *Palythoa* and apparently related to *Vibrio cholerae*. This vibrio reportedly is only mildly pathogenic to humans, causing a flu-like illness, and rapidly loses its ability to produce toxin. The *Palythoa* species containing palytoxin grows in a tide pool on the coast of Maui not far from Hana; by land, it is virtually inaccessible, and native fishermen avoid that part of the coast.

Palytoxin represents a challenge to molecular biologists who may wish to clone the gene(s) involved in synthesis of the toxin.

Many other marine biotoxins have been discovered and described, including a neurotoxic compound found in the digestive secretion of brachyuran decapod crustaceans. Under stress conditions, various species of crab from the Atlantic coast regurgitate their digestive secretion which, when in contact with seawater, produces large amounts of foam. This behavior probably reduces predation by other crabs. Like the other toxins produced by marine invertebrates, this is a form of chemical defense, a behavior not unlike that of some insects. Partly purified extracts of the digestive secretion of crabs resemble synthetic benzimidazole derivatives reported to have local anesthetic properties. Thus, the active local anesthetic present in extracts of the secretion may be of pharmacological value.

Hybridoma technology is proving invaluable for identifying, isolating, and characterizing marine toxins, as well as for producing diagnostic and therapeutic reagents for treatment. Hybridoma technology arose during the course of very basic, rather esoteric studies on the somatic cell genetics of immunoglobulin production by mouse myeloma cells. During experiments carried out to examine the regulation of expression of immunoglobulin genes, G. Köhler and C. Milstein fused cultured mouse myeloma cells to spleen cells of mice immunized with sheep red blood cells. Some of the hybrid cells containing the genetic material from both the myeloma and the normal spleen cells were found to produce antibody that reacted with sheep red blood cells.

The antibody-forming cells not only grew continuously in culture but also maintained other characteristics of the myeloma parent, in that they could be frozen and recovered alive from the freezer. When injected into recipient animals, these cells formed tumors that secreted large amounts of the antibody molecule accumulating in the serum and ascites of the tumor-bearing animals.

What Köhler and Milstein did was to immortalize a single antibody-forming cell: the progeny of that cell continued to produce large amounts of the antibody molecule that the original spleen cell had been producing prior to fusion. The beauty of this technology is that all the progeny of the hybridoma produce the same antibody molecule, so that the antibody is monoclonal and homogeneous.

Another fascinating substance is siphonodictine. This compound is the major secondary metabolite of an Indo-Pacific sponge (*Siphonodictyon* species) that burrows into living coral heads; it inhibits their growth and may be responsible for the zones of dead coral polyps found around the oscular chimneys of these sponges. Siphonodictine also has been found to have antibacterial properties.

Thus, the potential for engineering the production of these complex pharmaceuticals of marine origin poses a strong attraction for the pharmaceutical industry. The need at the moment is for strategies for collecting, culturing, and screening marine organisms from which bioactive agents can be isolated and characterized. Most likely, however, immediate successes will occur in discoveries of novel antibacterials or antibiotics produced by marine bacteria.

Industrial Chemicals

In the short term, it is more likely that marketable products will come from marine polysaccharides, carotenoids, and specialty chemicals such as unusual sugars, enzymes, and algal lipids. They represent products for rather immediate payoff.

Carrageenin, a major product from the red seaweeds, is already widely used as an extender in foods and related products from evaporated milk to

toothpaste. Agarose is widely employed in electrophoresis and chromatography analyses in the laboratory. Thus, specialty chemicals from salt-tolerant microbial systems (notably polysaccharides, enzymes, and lipids) offer the greatest potential industrialization for the immediate future.

Besides toxins, other biologically active substances, and those substances already exploited commercially, such as carrageenin, chitin, and agarose, a variety of interesting compounds and metabolites have been reported. These include spatane diterpenoids isolated from the tropical marine alga *Stoechospermum marginatum*, not yet observed from terrestrial sources, and a new polyether derivative of a C_{38} fatty acid called okadaic acid, isolated from *Halichondria* (syn. *Reniera*) *okadai* Kadota, a black sponge commonly found along the Pacific coast of Japan, and *H. melanodocia*, a Caribbean sponge found in the Florida Keys.

The structural features of okadaic acid suggest that it belongs to the class of compounds known as ionophores, hitherto known only from terrestrial microorganisms. It is likely that okadaic acid is a metabolite of an epiphytic microorganism, rather than of the *Halichondria* species. Structural studies of the marine toxins palytoxin and ciguatoxin indicate that these two compounds also possess many structural features normally associated with ionophores. In fact, T. Yamusoto has isolated okadaic acid from the dinoflagellate *Procentrum lima*, a likely progenitor of okadaic acid.

Sea hares offer the advantage of being rich sources of interesting metabolites, but the ultimate source of the latter is not always clear, often proving to be algae. Notable are the extracts of the sea hare *Aplysia dactylomela*, which show both cytotoxicity and *in vivo* antitumor activity, as well as a variety of halogenated metabolites.

Recently (1979), the cloning and expression of sea urchin histone genes, using SV-40 DNA as a vector, was reported by J. S. Kapstein and G. C. Fareed. Thus, the cloning of genes of marine animals has begun.

Biodegradation

In contrast to natural products, manmade compounds are relatively resistant to biodegradation, often because organisms naturally present cannot produce enzymes necessary to transform manmade compounds such that the resulting intermediates can enter into common metabolic pathways to be metabolized completely. This creates special problems for waste treatment and environmental protection.

Required steps to initiate biodegradation are reasonably well understood. Halogenated compounds, we know, are particularly persistent because of the location of the halogen atom, the particular halide involved, and the extent of halogenation. Selective use of microorganisms, including actinomycetes, fungi, bacteria, phototrophic microorganisms, anaerobic bacteria, and oligotrophic bacteria is a common practice in applications such as wastewater treatment for biological removal of nitrogen. Controlled mixed cultures—composed of heterotrophic bacteria, photosynthetic bacteria, and algae—are already in use in Japan for treating selected industrial wastes. Various methods of genetic engineering will certainly become widely used to develop optimized proliferation and maintenance of selected populations.

What has not yet been considered, however, is the engineering of microorganisms to be added to wastes that are to be discharged into the marine environment. It is obvious that, with increased use of the world oceans as disposal areas for man's waste, attention must be paid to the problems of marine pollution. Pollutants entering the ocean that can interfere with the integrity of ecosystems include synthetic organics, chlorination products, dredged spoil, litter, artificial radionuclides, trace metals, and fossil-fuel compounds. Toxaphene, a group of slightly less than 200 compounds produced by chlorination of wood waste-products and camphors under ultraviolet light, contains carcinogenic and mutagenic members and may be more persistent in the environment than DDT. Biodegradation of toxaphene by marine bacteria does not appear to progress rapidly, if at all.

The problems of in-situ degradation are much greater than for contained application. The modifications of genetic information resident in microorganisms that are useful in pollution control are: 1) amplification of enzyme concentrations in an organism, either by selection of mutants, increase in the number of copies of the gene for the enzyme, or both, 2) rearrangement of regulatory mechanisms controlling the expression of specific genes in response to specific stimuli, 3) introduction of new enzymatic functions into organisms not possessing them, and 4) alteration of the characteristics of specific enzymes, such as substrate specificity, kinetic constants (K_m and V_{max}), or factors such as pH optimum. To achieve these modifications, one can undertake *in vitro* recombinant DNA manipulation, or one of various types of *in vivo* genetic modification via transposon mutagenesis or other transposon-mediated gene manipulation. However, what has not been considered is how to engineer microorganisms so that they can flourish in the marine environment. Low temperatures, high salinity, relatively high pH (8.2), and, in the deep sea, elevated hydrostatic pressure are conditions that engineered microorganisms must survive if they are to be inoculated into recalcitrant wastes prior to ocean dumping.

From another perspective, the need for algicides and anti-fouling agents is so great that breakthroughs in obtaining compounds with these activities will guarantee huge market success.

Engineering microorganisms to deal with the specific problems of the seafood industry, such as disposal of shellfish waste, has not been considered. Conversion of one component of shellfish waste, chitin, to single-cell protein or for uses in the food industry, has been attempted. Thus, cloning the genes of the chitin complex offers a very promising area upon which focus by industry should offer pay-offs. Unfortunately, the industry developed to exploit chitin or its derivatives is relatively small. Two

companies in the United States produce chitosan, one of the derivatives of chitin. There is some production and marketing of chitosan in Japan.

Biotechnology and Aquaculture

Bioengineering applications in aquaculture have only recently begun and efforts to date are extremely limited, even though marine animals and plants represent a major opportunity as a food source for the future. In the United States, most of the traditional fisheries are being harvested at or near maximum sustainable yields. Approximately 60 percent of the fisheries products consumed in the United States are imported, representing a trade deficit in excess of $2.5 billion.

That aquaculture itself can pay off is already established. China, for example, produces 2 million metric tons of finfish every year, mostly carp grown in ponds, lakes, reservoirs, and ditches (see *Oceanus*, Vol. 26, No. 4, p. 33). In the United States, interest in aquaculture is on the rise, and that interest has meant increases in our knowledge of marine biology and the technical expertise needed to apply discoveries in marine biology to aquaculture. The United States has the opportunity to take the lead in applying sophisticated, more efficient methods for fish aquaculture. Interestingly, the National Sea Grant College Program has been at the forefront of many of this country's advances in aquaculture. Research has been underway for more than a decade on marine shrimp, freshwater prawn, crawfish, blue crab, brine shrimp, salmon and other finfish, oysters, clams, abalone, and scallops.

Disease is a major obstacle to successful culturing of fish and shellfish. Infectious pancreatic necrosis (IPN) of fish, is one example where modern methods of microbiology and immunology are being applied. The antigenic relationships of various IPN isolates are now being studied for the purpose of developing antisera and vaccines against the virus. Temperature-sensitive mutants of the virus also have been isolated to provide genetic information and possible sources of attenuated virus strains for use in live vaccines. The use of hybridoma technology will almost certainly pay off in the production of fish vaccines and IPN virus vaccine may well be the first to be successful.

An extract (Ete) from *Ecteinascidia turbinada* has been shown to enhance the hemocyte function of certain invertebrates, possibly rendering the animals more resistant to infection. Interestingly, intraperitoneal injection of Ete renders eel strongly resistant to *Aeromonas hydrophila* and appears to potentiate phagocytic activity. Ete also causes changes in the concentration of peripheral blood leucocytes.

Biotechnology offers extraordinary opportunities for aquaculture. Many species of shellfish and finfish are available in culture, providing excellent opportunities for selection and gene manipulation. Production, stabilization, and delivery of vaccines, employing both hybridoma technology and genetic engineering, should enhance productivity from the egg through the larval stages, presently the high-risk portion of the life cycle.

D. E. Morse and his colleagues at the University of California at Santa Barbara (UCSB) have developed techniques that improve production of abalone and other important commercial shellfish. The UCSB investigators have focused on abalone, the commercial value of which is $20 to $30 a pound in Santa Barbara. They have discovered that spawning in a number of molluscs is normally regulated by prostaglandins—hormones known to regulate reproduction in humans and other animals. The synthesis of prostaglandins can be accelerated and spawning induced simply by adding to the seawater a small amount of peroxide, which stimulates the natural enzymatic synthesis of the hormone and triggers the spawning response (Figure 1).

Figure 1. A male abalone (18 centimeters in length) is shown releasing sperm in response to hydrogen peroxide. The sperm are broadcast in jets of water expelled through the respiratory pores in the shell. As many as 10^{12} sperm may be released over a period of 30 minutes in a single spawning. Female abalone also are induced to spawn copiously by this simple and inexpensive method. (Appears on cover in full color. Courtesy of D. Morse, University of California, Santa Barbara)

Settlement of abalone larvae and metamorphosis was found to be triggered by the amino acid GABA. GABA, γ—aminobutyric acid, is a simple amino acid and potent neurotransmitter in the human brain and other tissues of higher animals. It rapidly and synchronously induces planktonic larvae of the red abalone, *Haliotis rufescens*, to settle and begin behavioral and developmental metamorphosis. GABA also activates the cell membrane to become permeable to certain ions, an important step in triggering cellular differentiation taking place during metamorphosis.

Morse and his colleagues are now working on cloning the genes that code for growth-accelerating hormones, for inexpensive production of the hormone and, potentially, direct genetic modification of the animals under cultivation (Figures 2 and 3).

Species identification and stock assessment of migrating fish are major, unresolved issues in fishery management. A method for comparing

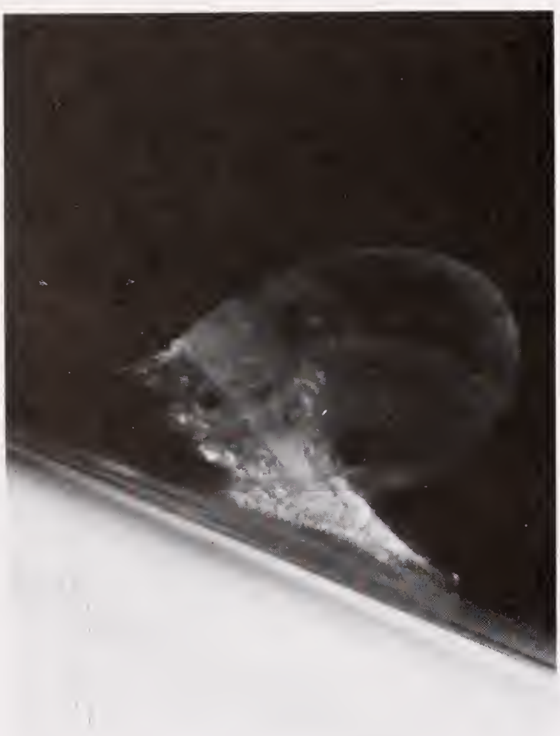

Figure 2. Larval abalone (0.2 mm), minutes after induction to settle from the plankton and begin development to the snail-like form of the adult, by the chemical signal, GABA. GABA (γ-aminobutyric acid) is a principal neurotransmitter in the human brain, where it bridges nearly half of all synaptic connections. Research at the University of California at Santa Barbara with the uniquely tractable abalone larvae first demonstrated that this neurotransmitter also plays an essential role in the control of genetically programmed embryonic development; such a role is likely to be exerted during the normal control of development of the human brain as well.

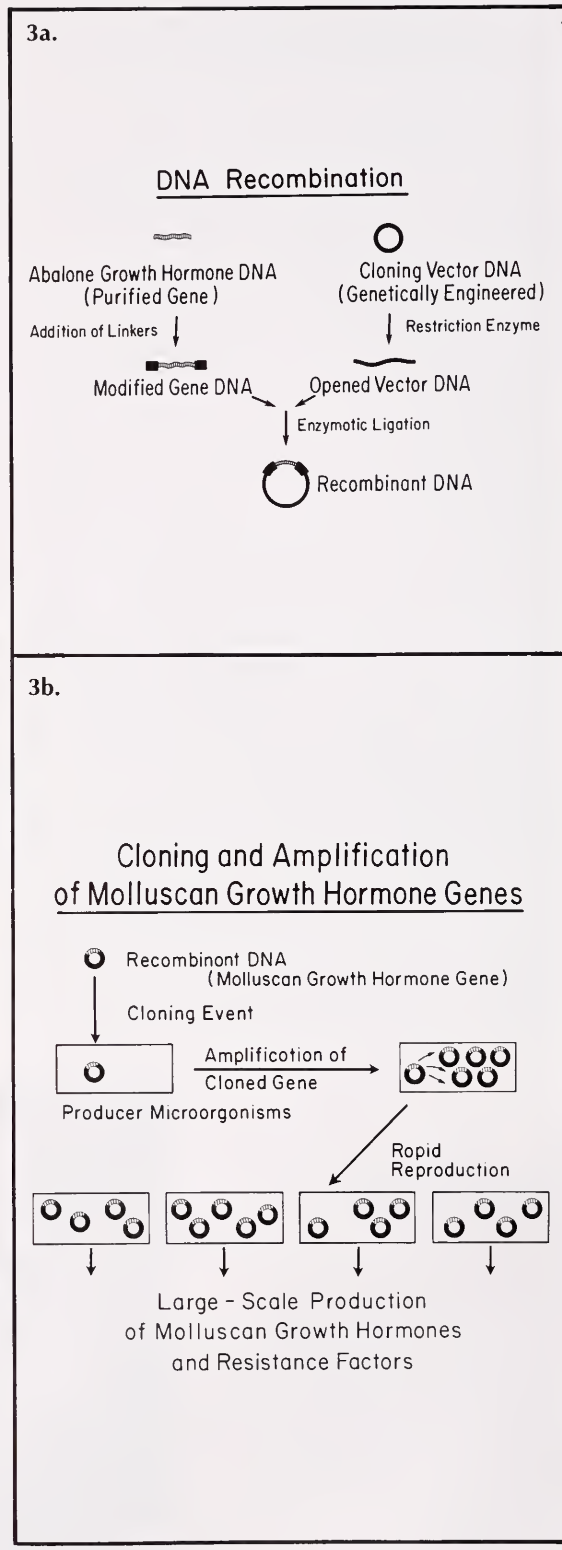

Figure 3a, 3b. Procedure for cloning and amplification of molluscan growth hormone genes. (Courtesy of D. Morse, University of California, Santa Barbara)

mitochondrial DNA (mt DNA) from different individuals offers an opportunity for mapping the mt DNA genome and is being explored by several investigators. The use of restriction endonucleases, which cleave DNA at sites specified by unique sequences of four, five, or six nucleotides, allows mt DNA, when digested by one of the enzymes, to be cut into a characteristic set of fragments of different lengths. The number and sizes of the fragments can be compared with those of other individuals in a pattern analysis. The method of using restriction digests to analyze mt DNA now allows investigation of evolutionary relationships among species and conspecific populations.

Applied to marine fishes and invertebrates, analysis of mt DNA may be the key to assessing the population structure of these animals. Genetic differences among fish species have already been successfully detected by analyzing the proteins in tissue extracts, but the possibility of using genetic marking by mt DNA pattern analysis or by introducing selected genetic traits into fish (as opposed to mechanical tags) is an exciting possibility. Fish wander over long distances without barriers to their movements, but this approach may be the way to detect subpopulations or specific independent stocks: these methods are very precise and yield unequivocal identification.

Marine plants offer special opportunities in aquaculture. For example, genetic engineering of osmoregulation is now being studied. Plants that grow in saline soil (haplophytes) can be very useful in agricultural areas where the soil has become too salty for conventional agriculture. Marine and estuarine grasses, if producible in abundance, are beneficial in managing erosion and shoreline losses.

A method for cloning marine red algae for inoculation of artificial substrates has recently been described (Figure 4, cells of *Porphyra*). Pure tissue culture of the marine brown alga *Laminaria angustata* has been established for the first time, reported by N. Saga and Y. Sakai in 1983. Commercially important chemicals from plant cells are being sought through an agreement to develop technologies appropriate to this task by International Plant Research Institute (IPRI), San Carlos, Calif. and the Davy McKee Corporation, Chicago. IPRI is a company that genetically engineers plants. Such efforts should be undertaken for other marine plants, especially since a variety of unusual compounds have been reported to be produced by marine algae, notably the red and green algae and marine grasses.

Biofouling

Fouling of surfaces in the marine environment is a costly burden for any operation carried out in or near seawater. The progressive steps involved in biofouling, from the first film of algae and bacteria, to attachment of invertebrate animals capable of boring and digesting the surface, have been documented in countless publications during the last century. The ability of bacteria to find, attach, adhere, elaborate specific film-forming substances, and regulate expression of all of these functions is fundamental to the fouling process. Fortunately, the tools of genetic engineering are well suited to analysis of the properties of bacterial cell surface components, since specific genetic elements determining the structure of specific polysaccharides and polypeptides can be isolated and the mechanism of cell-surface association probed so that appropriate steps for intervention can be taken.

Larvae of invertebrates have been shown to prefer to settle on surfaces coated with microbial films. Settlement and metamorphosis does not occur in the absence of microbial films, in the case of the tube-forming polychaete, *Janua* (*Dexiospira*) *brasiliensis*. *Janua* is a small (2 to 3 millimeters), hermaphroditic polychaete abundant on a variety of surfaces, notably *Zostera* (eel grass).

Planula larvae of the medusa *Cassiopeia andromeda* settle on a substrate, attach, form a pedal disc and metamorphose, that is, elongate, segregate stalk and calyx, and develop

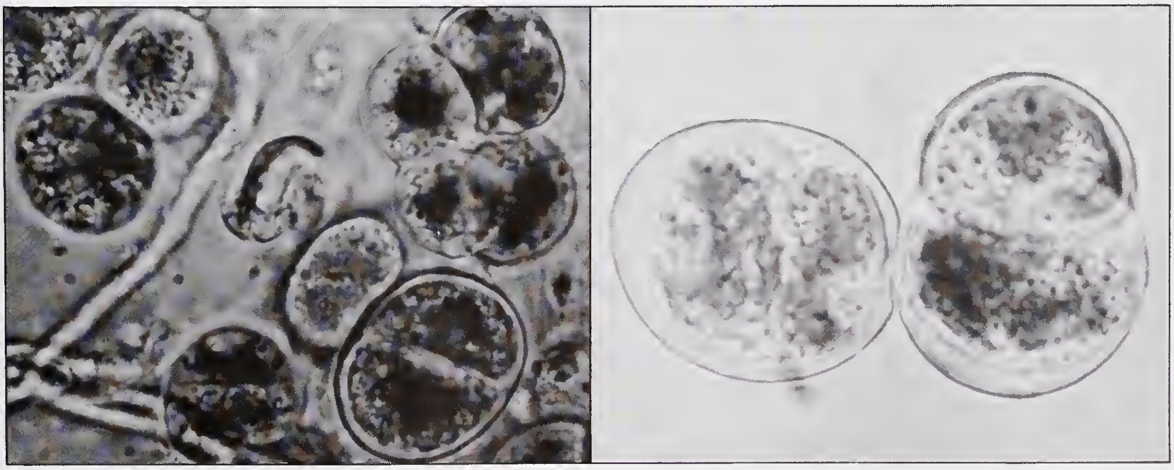

Figure 4. Isolated cells of Porphyra, *a red alga. Some cells have begun to divide. Cell size is approximately 50 micrometers. (Courtesy of M. Polne-Fuller, University of California, Santa Barbara)*

a hypostome and tentacle anlagen. Pedal-disc formation and metamorphosis were clearly shown to be initiated by substance(s) produced by a marine *Vibrio* species. The inducing factor is released into the culture medium by the bacteria.

A few years ago, a unique bacterium, which we call LST, was isolated from tanks containing oyster larvae at a mariculture unit in Lewes, Delaware. This organism is readily isolated from oysters and oyster beds and, interestingly, is associated with induction of settlement and metamorphosis of the oyster. The strain adheres very strongly to cultch and other hard surfaces, forming microcolonies on the cultch. In sufficient numbers, notably during the decline phase of growth, the bacterium produces a high concentration of pigment, sufficient to attract oyster larvae (Figure 5) and demonstrates a hormone-like, stimulatory effect on larval settlement and metamorphosis. Such a symbiotic relationship between an invertebrate and bacteria is common in the marine environment, as with, for example, the relationship between the sponge *Halichondria panicea* and *Pseudomonas insolita*.

Work done in collaboration with Ronald Weiner and Dale Bonar at the University of Maryland showed that melanin (and its precursors), with a brown pigment, and produced by the bacterial strain LST, acts as a metamorphosis-inducing agent for oyster larvae.

Figure 5. Larva of the oyster. Crassostrea virginica. *300X magnification.*

Research accomplished during the last 50 years has made it evident that planktonic larvae of benthic invertebrates settle and metamorphose in response to specific substances or conditions in their environment. In the absence of those substances, metamorphosis can be delayed indefinitely.

Thus, specific compounds of bacterial origin—for example, those related to melanin—can promote settlement and development of American oysters and of other marine invertebrates, including those of commercial value.

Several laboratories in the United States are now focusing on the various steps associated with biofouling, employing techniques of genetic engineering to develop anti-fouling agents by developing inhibitors that function at the molecular level. For the first time, the biofouling process is being examined by molecular geneticists and regulation of the process may very well be understood at last.

A fascinating aspect of the molecular biology of marine invertebrates presently being studied is protochordate allorecognition. Colonial tunicates, unlike vertebrates, undergo transplantation in nature. Rejection or acceptance of colonies has been shown recently to be controlled by a single gene locus with multiple alleles. The same genetic region apparently maintains this polymorphism by preventing fertilization between gametes sharing alleles. Thus, the histocompatibility system of marine invertebrates can provide a better understanding of the immune recognition of tissue antigens and rejection of transplanted allogenic organs, tissues, and cells in vertebrates, involving the major histocompatibility complex (MHC), since protochordate allorecognition is controlled by an MHC-like gene system, a sort of ancestral MHC gene complex.

Conclusion

The few examples offered here illustrate the immense potential of biotechnology applications to marine sciences that have industrial significance. A strong foundation exists, because of the rich marine biology research that has been done in the last century, for exploitation of biologically active compounds known to occur in the sea. Thus, there is genuine encouragement for exploration of the recesses of the world's oceans for compounds and food sources as yet undiscovered.

Applications of genetic engineering to the marine sciences offer access to an untapped gene pool for (besides those mentioned in this article) transport systems for minerals, metal concentration, novel photosynthetic systems, marine pheromones ("communicator substances" produced by marine animals), as well as the hydrogen sulfide-utilizing and microbially-mediated system of the Galápagos Vent ecosystems (see *Oceanus*, Vol. 25, No. 2, p. 22). A wealth of genetic information can now be gained and new knowledge of ourselves and of our oceans revealed.

Ironically, the long-touted potential of the oceans to serve as a significant source of protein for human populations will come closer to being realized on an even grander scale with the advent of the tools of genetic engineering. The scale of management and stock breeding, so successful for agriculture and domestic animals and livestock, can now be duplicated for fish and shellfish, which offer the advantage of significantly shorter generation times and maturation cycles.

The industrial promise of the oceans will reap profits, there is no question. Hopefully, the exploitation will be wise and carefully managed.

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Acknowledgments

The author wishes to acknowledge the assistance of her graduate students, postdoctoral fellows, and colleagues at the University of Maryland who have contributed over the years to the excitement and discoveries in marine microbiology and biotechnology, some of which has been cited in this article. I also would like to acknowledge the support of the National Science Foundation, the Office of Naval Research, the National Sea Grant College Program of the National Oceanic and Atmospheric Administration, and the National Institutes of Health.

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Discovery to Commercialization: The Blood of The Horseshoe Crab

by Thomas J. Novitsky

The story of the scientific contributions of the horseshoe crab, *Limulus polyphemus*, actually begins in the middle of the Cambrian period of prehistory, some 500 million years ago. From what paleontologists have gleaned from the fossil record, we know that several animals were quite common in Cambrian seas. These included the familiar trilobite, the less familiar eurypterid or giant water scorpion, and the earliest ancestor of the horseshoe crab, *Aglaspida*.

Several morphological features of these creatures were quite similar, reflecting their common ancestry. Each animal had two prominent compound eyes on its dorsal, and four to five pairs of walking and/or swimming legs on its ventral anterior body section. While these features identify the close relations among these prehistoric arthropods, both the water scorpion and horseshoe crab also possessed a conspicuous tail spine or telson, whereas only a few species of trilobite sported such an appendage.

Indeed, the horseshoe crab and giant water scorpion already were quite distinct from their cousin the trilobite, representing a large division of arthropods called the chelicerates. The chelicerates are distinguished from other arthropods by forelegs or chelicerae, which are specially adapted for feeding. Modern chelicerate representatives, besides the horseshoe crab, are the spiders and scorpions.

Thus, the horseshoe crab, in the taxonomic sense, is not a crab. The misnomer, only one of many found throughout the animal kingdom, is widely used and accepted.

Although the aglaspids of the Cambrian period were clearly recognizable as horseshoe crabs, these animals continued to evolve over the next 100 to 200 million years. By the late Jurasic period, *Mesolimulus*, the nearest ancestor of today's horseshoe crab to be found in the fossil record, had appeared. Fossils of this creature exhibit morphology virtually identical with that of the extant *Limulus* (Figure 1).

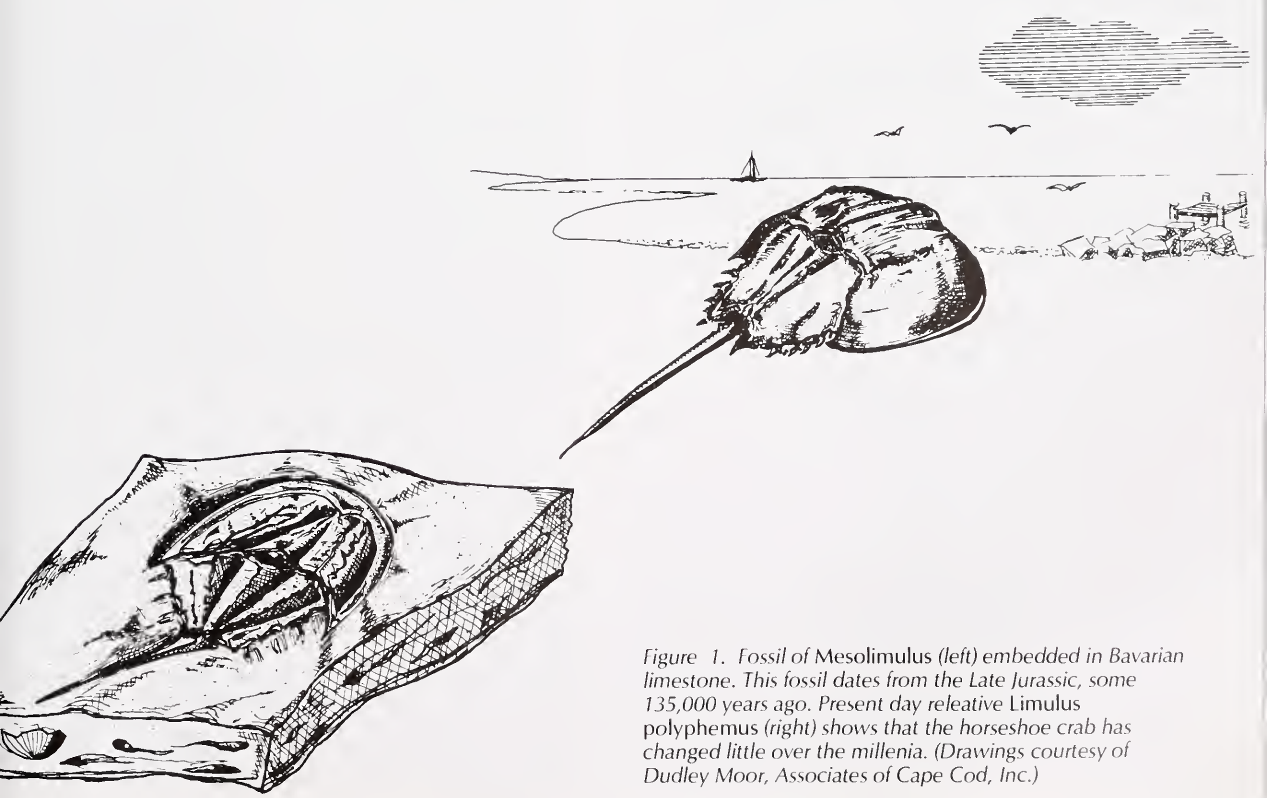

Figure 1. Fossil of Mesolimulus *(left) embedded in Bavarian limestone. This fossil dates from the Late Jurassic, some 135,000 years ago. Present day releative* Limulus polyphemus *(right) shows that the horseshoe crab has changed little over the millenia. (Drawings courtesy of Dudley Moor, Associates of Cape Cod, Inc.)*

The primitiveness as well as the unique morphology and abundance of the horseshoe crab was instrumental in attracting scientists to its study. Although the North American *Limulus* was first described by Thomas Hariot in 1588, it was not until the late nineteenth century that scientific inquiry concerning what Hariot called the "horsefoot" crab began. Early interest, of course, centered on the natural history and taxonomic position of this "living fossil," but soon embryologists and physiologists began to focus their attention on *Limulus*.

W. H. Howell of Johns Hopkins University described the clotting of *Limulus* blood in 1885, a finding fundamental to later discoveries involving the blood of the horseshoe crab. The Marine Biological Laboratory (MBL) in Woods Hole, created in 1888 and located near prime horseshoe crab breeding areas, soon became both the center for *Limulus* research and a principal source of horseshoe crabs for study.

Indeed, the MBL's Marine Resources Department (formerly called the Supply Department), has included since its earliest days a rendition of *Limulus polyphemus* as part of its departmental seal, and rightly so (Figure 2). Several eminent men of science conducted studies on the horseshoe crab at the MBL. During his tenure at Woods Hole, Leo Loeb extended the earlier work of Howell and described in elegant detail the blood and circulation of *Limulus*. Later, H. K. Hartline would receive the Nobel Prize for his studies on vision, specifically for his work on the optic nerve and vision of *Limulus*.

Figure 2. Seal of the Marine Resources Department of the Marine Biological Laboratory depicting Limulus polyphemus. *(Seal reproduced with permission of the Marine Biological Laboratory)*

Perhaps the greatest discovery concerning *Limulus*, however, occurred shortly after Frederik Bang appeared at the MBL in the 1950s. Bang discovered the causative agent for clotting of *Limulus* blood—the same agent missed by Howell in 1885 and again by Loeb some 30 years prior to Bang's arrival at the MBL. The medical potential of this seemingly "basic" scientific discovery was soon evident. With this discovery, the horseshoe crab, which had already contributed so much to the science of physiology, began to provide a more direct benefit to humankind. This benefit emerged in the form of a diagnostic reagent made as a by-product of Bang's initial discovery. The reagent, Limulus amebocyte lysate, or LAL, can detect minute amounts of bacterial toxins associated with certain bacterial diseases and the production of fever, shock, and death in humans and animals.

To understand the science leading up to Bang's discovery, studies conducted on bacterial toxins must be examined. Beginning in the early 1920s, at about the same time that Leo Loeb was studying horseshoe crab blood, other investigators were beginning to elucidate bacterial toxins, in particular those toxins that cause fever—the bacterial "pyrogens" or endotoxins. Great strides were made in this area between 1921, when it was recognized that bacterial endotoxin is responsible for both fever and the immunity associated with certain bacterial infections, and the early 1950s, with the isolation and chemical elucidation of the biologically active component of endotoxin, lipopolysaccharide (LPS). Although not all substances that cause fever are of bacterial origin, it soon became apparent that most, if not all, pyrogenic episodes related to intravenous therapy and many bacterial diseases were due to endotoxin. The terms "pyrogen" and "endotoxin" in a pharmaceutical sense, therefore, are often used synonymously.

Endotoxin occurs as a structural component of the cell wall of a large group of bacteria that do not retain the dye, crystal violet, when stained by the method of Christian Gram. This bacterial group is referred to as gram-negative. Most aquatic bacteria, marine as well as freshwater species (including those found in drinking water), are gram-negative. As these bacteria grow they constantly "shed" endotoxin. When they die, additional endotoxin is released into the water.

In the treated water used for drinking and pharmaceutical manufacturing, most bacteria have been killed, but their endotoxin remains, often in large quantities. It is no wonder, then, that drug solutions were so frequently contaminated with endotoxins.

It also is intriguing to note that the horseshoe crab lives in a veritable soup of gram-negative bacteria and endotoxin. Work done at the Woods Hole Oceanographic Institution (WHOI) has shown that upwards of one million gram-negative bacteria per milliliter inhabit the water, and nearly one billion bacteria can be found per gram of sand in nearshore areas. These same areas also serve as home for *Limulus polyphemus*. It is likely, then, that the

reaction of *Limulus* blood to endotoxins (and gram-negative bacteria) is a sort of primitive immune system that has helped the horseshoe crab survive infection over the millenia.

It also is interesting to note that endotoxin, specifically the active component LPS, is extremely resistant to destruction or removal. Solutions for intravenous use therefore require careful preparation to exclude endotoxin. Water is usually distilled and collected in specially sanitized containers. Active drug ingredients are chemically purified and bottles used to contain the final solution are often treated with dry heat at temperatures exceeding 200 degrees Celsius. The commonly used methods for the terminal sterilization of solutions—moist heat under pressure (steam sterilization) and filtration—are inadequate for the destruction or removal of significant amounts of endotoxin.

Recognizing this, the U.S. pharmaceutical industry, through their representative, the United States Pharmacopeial Convention, Inc., requires that medications used intravenously be not only sterile but also nonpyrogenic.

To this end, the U.S. Pharmocopeia (USP), in 1941, included a method for testing solutions for the presence of pyrogens. This method called for the injection of the test solution into the bloodstreams of several rabbits and the subsequent monitoring of the rabbits' temperatures over a period of three hours. The rabbit, like the human, responds to pyrogens by developing a fever, shock, or complications resulting in death depending on the endotoxin dose. Batches of drugs that caused even a fever in rabbits were rejected and only those that passed the "rabbit test" were released for use.

The USP pyrogen test is still employed today much the same as first described. However, Bang's 1955 discovery that horseshoe crab blood clotted in the presence of pyrogen indicated that an alternate method of pyrogen detection was feasible. Indeed, Bang, later joined by Jack Levin, was able to design such a method. In their 1964 publication, "The Role of Endotoxin in the Extracellular Coagulation of Limulus Blood," Levin and Bang described a procedure for preparing an aqueous extract from ruptured *Limulus* blood cells (amebocytes). This extract, called "pre-gel" by Levin and Bang, would come to be called Limulus amebocyte lysate. As predicted soon after the first description of this test, LAL began to replace the rabbit for the detection of pyrogens.

I cannot give adequate credit to Bang, who, with superior insight and wisdom, was able to identify bacterial endotoxin as the causative agent of *Limulus* blood clotting. Bang often referred to his discovery as an example of serendipity—that is, a discovery resulting from a combination of chance and sagacity. In his last formal lecture, given at an international conference on LAL at Woods Hole in 1981, Bang defined the "rules governing serendipity" and gave other examples of fortunate scientific discoveries similar to his discovery of LAL. The discovery of LAL remains not only a superior example of serendipity, however, but one of the premier discoveries in marine biological science.

Commercialization

The commercial development of LAL can be traced back to Woods Hole in the early 1970s. At this time, the greatest interest in LAL was not for the testing of drug solutions but rather for use in diagnosing diseases caused by gram-negative bacteria. Just as many aquatic bacteria are of the gram-negative type, so are many pathogenic or disease-causing bacteria. Fortunately, endotoxin from either group is readily detected by LAL.

With this in mind, Jack Levin and his colleagues attempted the LAL diagnosis of gram-negative bacteremia—a bacterial infection of blood. The publication of their findings set off a flurry of research on the diagnostic applications of LAL.

Among the early supporters of the diagnostic usefulness of LAL was Jacob Fine of the Harvard Medical School. It was through Fine that Stanley Watson, a scientist at WHOI, learned of LAL. Watson's interest in LAL was quite removed from the diagnosis of disease: in his laboratory, Watson was trying to purify certain membrane components from a marine bacterium. The LAL reagent appeared to be a convenient way of assessing the purity of these components, since lack of endotoxin would signify the absence of cell-wall material, a common contaminant. Unfortunately, LAL was in short supply, and certainly not sensitive enough to detect very small amounts of endotoxin, as needed to assess the purity of membrane preparations.

Watson, therefore, decided to make his own LAL and in the process try to improve the reagent's sensitivity. This effort, to which Watson decided to devote "a couple of weeks," soon grew into a major research project.

Joined by James Sullivan in 1973, Watson's group was soon turning out good quality, highly sensitive LAL. At the same time, other investigators were finding out that the use of LAL in their experiments was prohibitive unless they made a major commitment in funds and personnel to produce LAL themselves. The WHOI source was soon discovered, however, and LAL from Watson's laboratory found its way to labs around the world. Once again, a basic research application took a turn no one had anticipated.

Recognizing a market for LAL, Watson approached the administrations of WHOI and the MBL with an idea for the commercialization of LAL. In his plan, Watson would set up a production facility and profits from the sale of LAL would go to support basic research. WHOI already owned the patent rights to a solvent-extraction process developed by Sullivan and Watson in their attempts at improving the sensitivity of LAL, and the MBL had all this time been supplying live horseshoe crabs to investigators attempting to make their own LAL. The idea, although feasible (and quite ahead of its time), was dismissed by both WHOI and the MBL since neither organization wanted to jeopardize its nonprofit tax status.

Watson's idea for the commercialization of LAL also was rejected by some biological-reagent manufacturers. Undaunted, Watson decided to commercialize LAL himself. In 1974, with James

Sullivan as director and armed with the patent purchased from WHOI, Watson began Associates of Cape Cod, Inc. (ACC). Ironically, some of the firms contacted in the initial attempt to market LAL belatedly decided that Watson's idea was sound and went on to become competitors of ACC. Watson's strong commitment to research and ground-level entry into the marketplace, however, assured ACC's initial and continued success. At present there are eight companies licensed by the U.S. Food and Drug Administration (FDA) to make LAL. Of these eight, ACC received the first license in 1977.

As the government agency assigned the task of enforcing the Federal Food, Drug, and Cosmetic Act, the FDA during the early 1970s also became interested in LAL as an alternative to the rabbit pyrogen test. Three scientists, in particular, can be credited with governmental acceptance of LAL for use in the pharmaceutical industry. They were H. Donald Hochstein and Edward B. Seligmann, Jr., at the FDA Bureau of Biologics (now the Office of Biologics), and James Cooper of Johns Hopkins, who came to the FDA Bureau of Radiological Health to pursue a master's degree.

Cooper, having learned the LAL test first-hand from Jack Levin, quickly introduced Hochstein and Seligmann to LAL's usefulness. In 1970, Cooper was able to demonstrate that the LAL test was a feasible pyrogen test for drugs. Cooper's specific contribution, use of LAL for testing short-lived radiopharmaceuticals, was finally made an official part of the U.S. Pharmocopeia in 1983—a fine tribute to this LAL pioneer.

The Bureau of Biologics also assumed the task of regulating the LAL supply to insure uniform quality of the reagent and continued survival of the natural resource—*Limulus.* One noteworthy event concerning LAL and the FDA came about in 1976 when certain lots of influenza vaccine were found to be heavily contaminated with endotoxin. It was LAL, not the rabbit, that actually turned up the contamination. Because of this event, federal regulations now require a test for endotoxin content in addition to a pyrogen test prior to the release of influenza vaccine. Accompanying this requirement was the first official FDA recognition of LAL for use with a drug product. Following guidelines published jointly in 1977 by the Bureau of Biologics for use of LAL with blood products and vaccines and the Bureau of Medical Devices for use of LAL for testing syringes and other disposable equipment, the pharmaceutical community began using LAL in lieu of the USP rabbit test.

Production

With FDA acceptance, use of LAL increased dramatically and production of LAL increased proportionally. At ACC, LAL production is seasonal, beginning in the spring with the appearance of the horseshoe crabs ending their winter hibernation and returning to the Cape beaches to spawn. A typical female *Limulus*, during periods of spring tides, will lay more than 80,000 eggs in nests containing about 3,000 eggs each. During this time, the horseshoe crabs can be easily collected in shallow waters, where mating pairs are found spawning (Figure 3). Fortunately for the horseshoe crab, an interruption of breeding does not have much effect on the reproductive cycle. Once returned to the water, the female crab will return to the beach, find another mate, and resume egg laying.

Later in the season, the *Limulus* migrates to deeper waters to feed on worms and small shellfish. Although regarded as a shell-fish predator and capable of crushing the shell of a modest-size clam, little is known about the horseshoe's dietary preference or its impact on the shellfishing industry. Because of its predator status, the horseshoe crab is held in low regard by most fishermen. Its use as eel and conch bait therefore is considered the "perfect solution" for ridding New England waters of this "pest."

That the horseshoe crab should be held in such low esteem is nothing new. The Commonwealth of Massachusetts actually paid a bounty for dead horseshoes around the turn of this century. Tons of horseshoe crabs also have been ground up for fertilizer, although this practice has

Figure 3. A pair of barnacle-encrusted mating Limuli *on a Cape Cod beach near Woods Hole. The larger female in the lead actually tows the smaller male from nest to nest. In the course of one season, the female will lay some 80,000 eggs in nests of 3,000 to 4,000 eggs each. (Photo by author)*

ceased on any large commercial scale. Since the Atlantic states do not regulate the taking of horseshoe crabs, little is known of the present population of *Limulus* or the number killed each year. It would seem that more ecological study and certainly some regulation of *Limulus* is necessary if its contributions to medical science are to continue.

To this end, we should take serious note of what almost happened in Japan. There, due to overfishing and pollution, the horseshoe crab was almost obliterated. Fortunately, the Japanese government now regulates the taking of horseshoe crabs. Furthermore, "Kabutogami" (as the Japanese commonly refer to this animal), is regarded as a national monument—a designation befitting its importance to mankind.

Recognizing the true value of the horseshoe crab, ACC makes an extraordinary effort to insure the animals' survival. Specially selected collectors deliver large adult crabs to ACC's laboratories daily. There the crabs are bled via heart puncture (Figure 4). The blood is collected in bottles and is subsequently centrifuged to separate the amebocytes from the plasma. The LAL reagent is really a complex mixture of proteins and salts whose origin is the amebocyte, the only type of blood cell present in *Limulus*.

The other blood component, the plasma, having no commercial value at present, is discarded. The plasma contains a copper-based respiratory pigment, hemocyanin, which imparts a rich blue color to the blood, a fact that has caused *Limulus* to be referred to as "New England's original blueblood." Once bled, horseshoe crabs are returned to the ocean near the collection site. Tagging studies have shown no significant difference in the survival of bled versus nonbled crabs, a finding similar to results of human blood donor studies.

From aquarium studies we know that a bled *Limulus* (up to 30 percent of the blood volume can be collected) regains its blood volume very quicky, usually in three to seven days. Amebocytes regenerate more slowly, requiring three to four months for cell counts to equal those obtained prior to bleeding. Aquarium horseshoe crabs have been successfully bled three times a year without any known deleterious effect to the animal. At ACC no horseshoe crab is bled more than once in a single season. The occasional crab that is recaptured in the same year is easily recognized by the needle scar that remains after bleeding.

After the amebocytes have been collected and washed free of any plasma components, they are broken open with the addition of distilled water. This procedure, called lysis, works because the ionic content inside the cell is much greater than that of the surrounding water. This concentration difference causes a relatively greater internal pressure that ruptures the amebocyte. Thus, the term "Limulus amebocyte lysate" is a very descriptive one, denoting both the source and the method of manufacture of the LAL reagent.

To activate raw LAL, additional ions must be added in the form of sodium and calcium or magnesium salts. To improve the reagent's sensitivity, a patented solvent extraction is performed. Finally, for long-term stability of the reagent, the final liquid LAL is freeze-dried. Prepared in this manner, LAL is capable of detecting as little as one-millionth of a gram of endotoxin and is stable for more than four years.

Figure 4. Limulus polyphemus *is bled via heart puncture using a large gauge needle. The blood or hemolymph containing the amebocytes is collected by gravity into a centrifuge bottle. Up to 30 percent of the horseshoe crab's total blood volume can be collected in this manner without adversely affecting the crab. After its "donation" the animal is returned alive to the ocean. (Photo by author)*

The LAL test is elegantly simple. A small amount of the LAL reagent is mixed with an equal amount of test solution in a glass test tube. The mixture is then incubated for a period of time, usually one hour at 37 degrees Celsius. At the end of this period the mixture is examined for the presence of a gel or clot. This clot is quite solid and will withstand inversion of 180 degrees Celsius. The clot is indicative of the presence of endotoxin or pyrogen (Figure 5).

Application

The major use of LAL today is for pyrogen testing of pharmaceutical products. Because the test is simple to perform and much less expensive than the USP rabbit test, pharmaceutical manufacturers perform more pyrogen tests. This has resulted in a dramatic improvement in the quality of drugs and biological products for intravenous injection. Since LAL can detect endotoxin concentrations below the

Figure 5. The LAL test for pyrogens is easily performed. The test tube (top), developed a solid gel after a sample was incubated in the presence of LAL reagent, indicating the presence of pyrogen or endotoxin. Samples free of pyrogen remain liquid (lower tube). (Photo by author)

pyrogenic level, pharmaceutical manufacturers are now able to tell well in advance if potential contamination problems exist with their products. In addition, it is now possible to screen raw materials and water prior to use in complex and expensive drug formulations.

Although touted in the early literature as a potential diagnostic tool for bacterial disease, the LAL reagent has not found widespread use in this area. One reason for this is that although the LAL reagent is exquisitely sensitive to endotoxin, it cannot differentiate between species of endotoxin—often a necessity for successful antibiotic therapy. This is not to say that LAL has not contributed to diagnosis of disease and saving human life. In perhaps its most successful clinical application, LAL has been used for the rapid (15 minute) diagnosis of gram-negative spinal meningitis.

Routine bacteriological analysis of spinal fluid takes from 24 to 48 hours. In at least one documented case, meningitis was diagnosed by LAL and was missed by bacteriological testing. Early studies have shown that LAL also could rapidly and accurately diagnose urinary tract infections. In another clinical application, LAL is used to diagnose endotoxemia in neonates. Until LAL became available for this use, it was extremely difficult for the clinician to diagnose endotoxemia of the neonate since in the premature infant the classical symptoms of this disease are not apparent.

One recent and fascinating clinical application for the LAL reagent is for the diagnosis of gonorrhea. The bacterium responsible for this disease, *Neiserria gonorrhea*, is gram-negative and possesses an endotoxin that is extremely reactive with LAL. Some recent research also has shown some promise for the diagnosis of infections of the eye and joints, using LAL on fluids from these sources. Use of LAL for the diagnosis of bacteremia, unfortunately, has not become widespread. The major reason for this is that substances present in blood interfere with the LAL test. The removal of these LAL "inhibitors" has frustrated would-be application of LAL to diagnosis of this disease. Research on this application at ACC and elsewhere is ongoing and the original diagnostic use of LAL predicted by Levin and Bang in their early papers may yet become reality.

It is easy to see that the horseshoe crab, having survived these millions of years, has made and is still making tremendous contributions to medical science. LAL alone has tremendously improved the quality of human life—indirectly through the assurance that drugs are free of pyrogens and directly through the diagnosis of disease. New applications for LAL continue to be found. For example, LAL has been shown to be useful for the detection of bacterially contaminated meat, fish, and dairy products, including frozen-food items.

The story of LAL, as a premier example of discovery, application, and commercialization of medically related products from the sea, should encourage us to take a more critical look at the ocean and its inhabitants. As Lewis Thomas wrote, commenting on a *Limulus* conference held at Woods Hole in 1978 and on Bang's discovery in particular: "The world is filled with creatures to study, all fascinating when approached closely enough. I trust that . . . skillful observers exist as well, and that more of the latter are needed to deal with more of the former."

Thomas J. Novitsky is Vice President and Director of Research at Associates of Cape Cod, Inc., where he has been employed since 1978. He worked with Dr. Watson at the Woods Hole Oceanographic Institution, where he learned about the Limulus amebocyte lysate (LAL) test first hand. Dr. Novitsky has published numerous articles and papers on LAL and recently co-edited a book on the subject.

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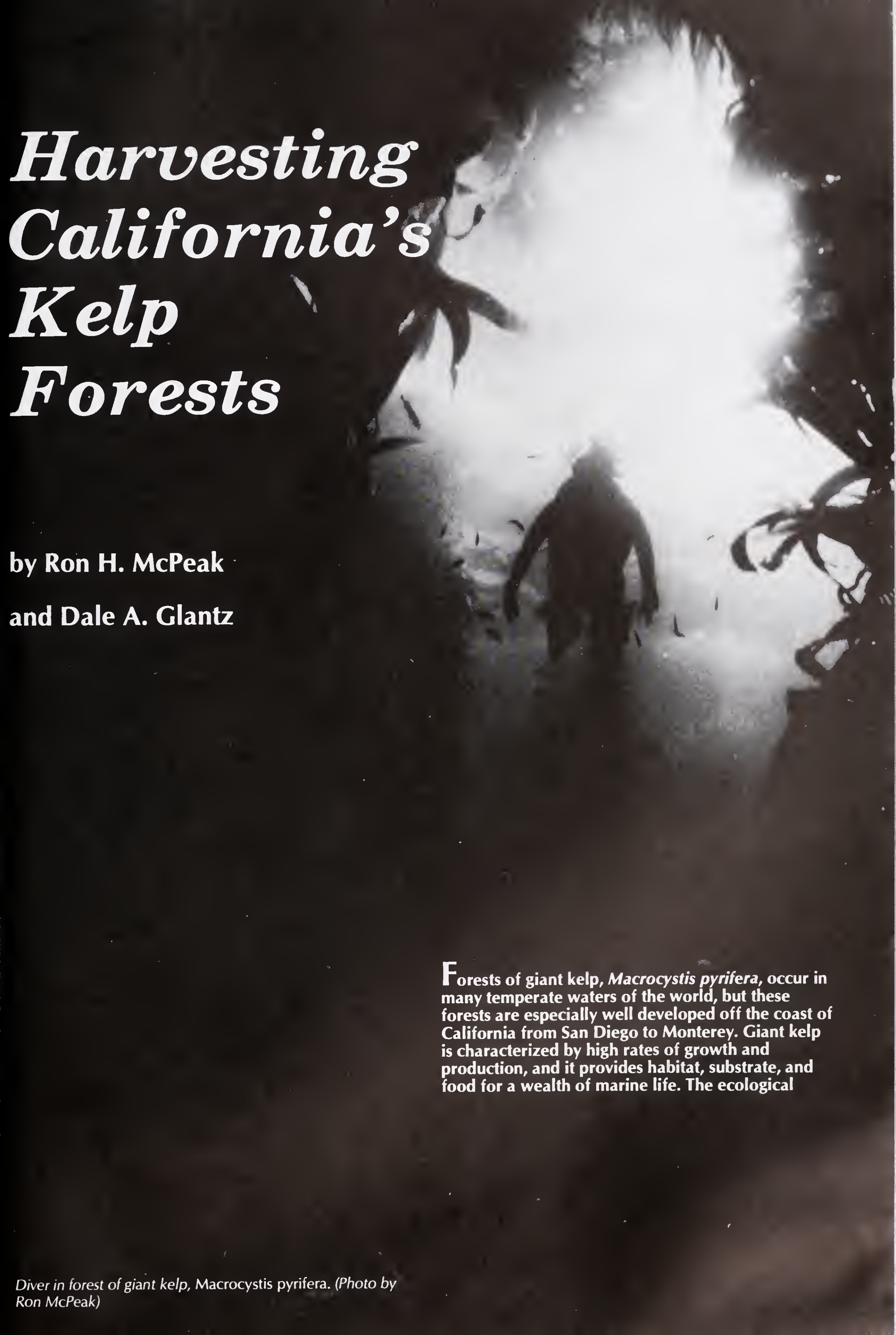
Harvesting California's Kelp Forests

by Ron H. McPeak

and Dale A. Glantz



Forests of giant kelp, *Macrocystis pyrifera*, occur in many temperate waters of the world, but these forests are especially well developed off the coast of California from San Diego to Monterey. Giant kelp is characterized by high rates of growth and production, and it provides habitat, substrate, and food for a wealth of marine life. The ecological

Diver in forest of giant kelp, Macrocystis pyrifera. *(Photo by Ron McPeak)*

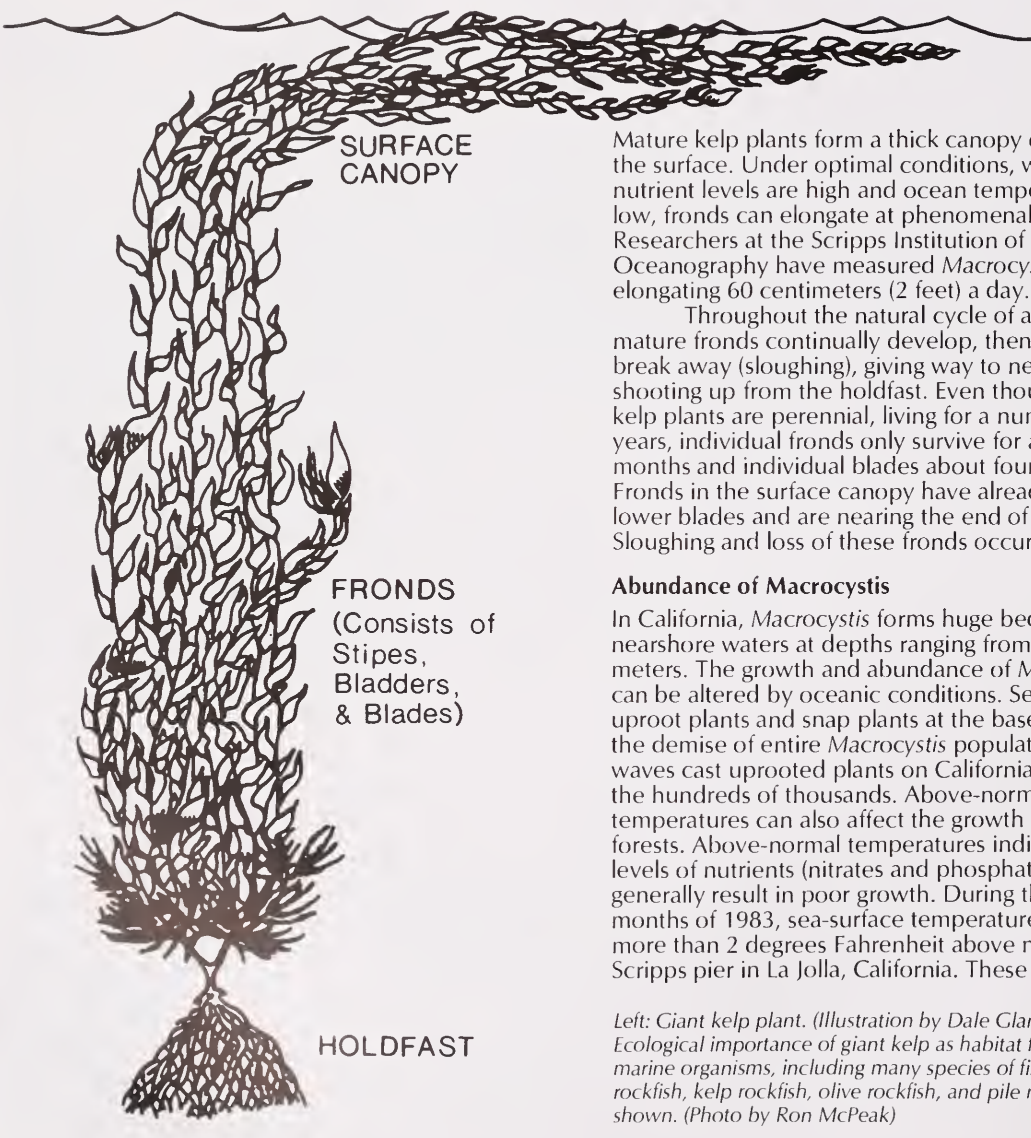
importance of kelp forests was noted by Charles Darwin in 1834, during the *HMS Beagle's* visit to Chile:

> *The number of living creatures of all Orders, whose existence intimately depends on the kelp, is wonderful. A great volume might be written, describing the inhabitants of one of these beds of seaweed . . . I can only compare these great aquatic forests . . . with the terrestrial ones in the intertropical regions. Yet, if in any country a forest was destroyed, I do not believe nearly so many species of animals would perish as would here, from the destruction of the kelp.*

The marine forests of California not only create a unique ecosystem for a myriad of animals, but also benefit man in a variety of ways. Giant kelp contains iodine, potassium, and other minerals, vitamins, and carbohydrates, and has been used for years as a food supplement. Of more value, however, kelp is the principal source of algin, a natural substance obtained from the processing of kelp, with the special ability to control large quantities of water. Algin is important to many industries as a highly efficient thickening, stabilizing, suspending, and gelling agent.

Growth of Macrocystis

Giant kelp has no root structure as found in land plants. Instead, kelp has a complex of branching, pencil-sized strands called a holdfast that cling to the ocean floor. Fronds originate at the base of the plant, near the holdfast, and eventually grow to the surface. The fronds are composed of a stemlike stipe and numerous blades that attach to the stipe by a short pedicel. At the base of the blades, gas-filled bladders serve to float the fronds away from the bottom. While land vegetation takes most of its nourishment through its roots, giant kelp absorbs nutrients from the water through all its surfaces.



Mature kelp plants form a thick canopy of fronds on the surface. Under optimal conditions, when nutrient levels are high and ocean temperatures are low, fronds can elongate at phenomenal rates. Researchers at the Scripps Institution of Oceanography have measured *Macrocystis* fronds elongating 60 centimeters (2 feet) a day.

Throughout the natural cycle of a kelp plant mature fronds continually develop, then die and break away (sloughing), giving way to new fronds shooting up from the holdfast. Even though giant kelp plants are perennial, living for a number of years, individual fronds only survive for about six months and individual blades about four months. Fronds in the surface canopy have already lost their lower blades and are nearing the end of this cycle. Sloughing and loss of these fronds occurs naturally.

Abundance of Macrocystis

In California, *Macrocystis* forms huge beds in nearshore waters at depths ranging from 6 to 36 meters. The growth and abundance of *Macrocystis* can be altered by oceanic conditions. Severe storms uproot plants and snap plants at the base, causing the demise of entire *Macrocystis* populations. Storm waves cast uprooted plants on California beaches by the hundreds of thousands. Above-normal ocean temperatures can also affect the growth of kelp forests. Above-normal temperatures indicate low levels of nutrients (nitrates and phosphates) and generally result in poor growth. During the first 10 months of 1983, sea-surface temperatures averaged more than 2 degrees Fahrenheit above normal at the Scripps pier in La Jolla, California. These above-

Left: Giant kelp plant. (Illustration by Dale Glantz). Right: Ecological importance of giant kelp as habitat for a variety of marine organisms, including many species of fishes; blue rockfish, kelp rockfish, olive rockfish, and pile rockfish are shown. (Photo by Ron McPeak)

Giant kelp plant uprooted by winter storms. (Photo by Ron McPeak)

normal temperatures were associated with the El Niño condition.

The combination of severe storms and El Niño conditions during 1983 resulted in poor *Macrocystis* development throughout most of California. In many areas where kelp forests were affected by the severe oceanic conditions, the recruitment of juvenile plants has occurred, which will help provide future canopies when conditions return to normal.

A variety of animals, including the sea urchin, also can affect the abundance and distribution of kelp. Under normal conditions, sea urchins feed on drift algae, which becomes available through natural processes of kelp dislodgement and degradation. Giant kelp of all stages is grazed and destroyed when urchins become overpopulated or when there is a reduction in the availability of drift material. David Leighton and Wheeler J. North, both formerly at Scripps, documented massive migrations of sea urchins off the coast of San Diego in the early 1960s. Leighton recorded the destruction of 1.6 hectares of *Macrocystis* during a 2-month period as urchins moved through the forest at a rate of 10 meters a month.

Uses of Macrocystis

Utilization of the California kelp forests actually began during the early 1900s. Kelp long had been used by coastal inhabitants of Asia and Europe as fertilizer and a source of potash. During the late 1800s and early 1900s, the United States obtained nearly all of its potash from the Strassfurt mines of Germany, and American farmers became dependent on this supply as a source of fertilizer. Congress initiated studies to determine domestic availability of potash, availability that would free the United States from dependency on Germany. Studies were conducted by the Department of Agriculture (1911 to 1913) to determine the abundance of kelp along the western coast of North America, available as a source of potash. These studies resulted in the Department of Agriculture Report No. 100: "Potash from Kelp" (Crandall, 1915), a publication that described the location and abundance of West Coast kelp.

At the same time that Crandall conducted his studies, harvesting was begun in California. The period 1911 to 1919 was a time of feverish harvesting activity, induced by the high cost of potash during years up to and including World War I. Many companies operated from San Diego to Santa Barbara. These companies extracted potash and acetone from kelp for the production of explosives. In 1916, the Hercules Powder Company was constructed near San Diego and reportedly employed 1,500 people, handling as much as 1,800 metric tons of kelp daily.

With the signing of the armistice in November, 1918, the price of acetone and potash dropped so low that most companies were forced to

Three species of sea urchin causing destruction of giant kelp by grazing. These red, purple, and white sea urchins are feeding on the holdfast and basal fronds of a plant at Point Loma. (Photo by Ron McPeak)

close. Government explosives contracts were canceled and kelp harvesting nearly ceased by 1919. Despite the general collapse of the kelp industry, there was an effort to market some by-products. Sales for these by-products were poor, production costs were high, and little success was realized.

There was almost no harvesting of *Macrocystis* from 1919 through the late 1920s. Philip R. Park, Inc., of San Pedro, began harvesting on a commercial scale in 1928. The company blended kelp meal and other ingredients for use as stock and poultry food. The real rebirth of the California kelp industry in the late 1920s, however, was the result of a discovery made many years earlier by E. C. C. Stanford, a British pharmacist. In 1883, he described a unique substance that he extracted from kelp. The substance was algin, a natural compound contained in the cell walls of kelp, with a special ability to control the properties of mixtures containing water.

Kelco Company of San Diego, the world's first producer of algin products, was founded in 1929, and has harvested and processed *Macrocystis* regularly since that time. Kelco is now a Division of Merck & Co., Inc., and, in addition to the San Diego plant, also processes other species of seaweeds at two Kelco/AIL sites in Scotland—Girvan and Barcaldine.

Initially, Kelco produced kelp meal, a milled, dried form of *Macrocystis*, for livestock feed. Soon thereafter, Kelco began to extract algin from freshly harvested kelp. The fresh kelp was unloaded, chopped, cooked, and further processed to yield this unique compound, algin, first used to control the viscosity in a gasket compound for sealing tin cans. Through continued research, Kelco developed many applications for algin. The company presently manufactures about 70 different algin products for literally hundreds of different uses.

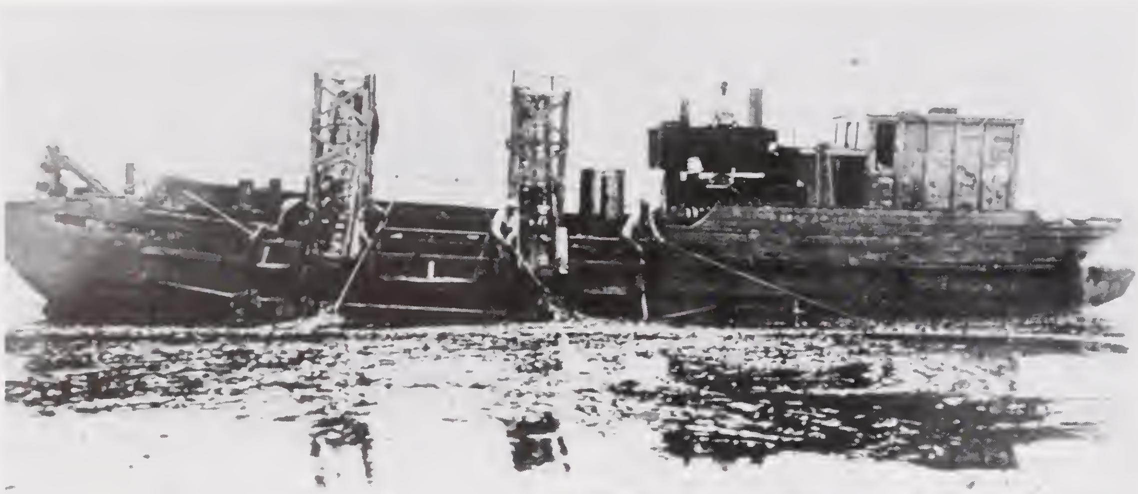
Algin is used in a wide range of foods, including desserts, gels, milkshake mixes, dairy products, and canned foods. Salad dressings are emulsified and stabilized with algin. In bakery products, from cake mixes to meringues, texture is improved and moisture is retained with algin. In frozen foods, the stabilizing properties of algin assure smooth texture and uniform thawing. Beer-foam stabilization is one of the more unusual functions performed by algin.

The primary industrial applications of algin products are paper coating and sizing, textile printing, and welding-rod coatings. Important uses also are found in pharmaceutical and cosmetic products. Examples include tableting, dental-impression compounds, and anti-acid formulations.

Alginates can be found in a variety of food and beverage applications, from beer-foam stabilization to structured frozen foods. (Courtesy of Kelco)

Giant kelp is habitat for a multitude of invertebrates, including the colorful nudibranch, Flabellinopsis iodinea *(Photo by Dale Glantz)*

Textile print pastes containing algin provide excellent ink-migration control for fine line printing. (Courtesy of Kelco)



Early harvesting techniques aboard the Pinole, *1936. Crew pulled giant kelp aboard vessel by hand. (Courtesy of Kelco)*

The modern harvester, Kelmar, *loading giant kelp. The vessel is being pushed through the kelp forest by a bow propeller. (Courtesy of Kelco)*

Algin is extremely important. It provides significant economic benefit to these industries and product utility to the consumer. In some uses, there is no satisfactory substitute for algin.

Kelco's harvesting, manufacturing, and research operations require a substantial work force. Kelco presently employs about 1,600 people worldwide; about 600 of these employees are located in San Diego. The annual sales of algin products manufactured in California exceed $35 million.

Harvesting Techniques

Several methods of harvesting kelp were developed during the early years (1911 to 1919). The most primitive method was to gather beach litter washed ashore as a result of storms. Some companies cut fronds by hand and either let them drift or towed them ashore. The most common method involved using a cutting pole, then pulling the kelp aboard a boat or barge. One of the more destructive methods involved encircling a portion of a kelp bed with a cable and then pulling the plants into a bundle with the use of power.

The mowing method of harvesting was developed around 1916 to help supply larger quantities of fresh kelp. Harvesting devices employed the principle of the hay mower, which involves reciprocating blades. The blades were mounted at the base of a conveyor system and lowered beneath the surface to a depth of about 1 meter. The reciprocating blades cut the kelp as the barge was pushed slowly by a boat through the kelp bed. The cut kelp was brought aboard the harvester on the conveyor, chopped into small pieces and conveyed to a barge that was later towed to the factory.

Present day harvesters also cut *Macrocystis* canopies with reciprocating blades mounted at the base of a conveyor system. Modern harvesters have the conveyor system (drapers) mounted on the stern of the vessel. When the harvester arrives at the kelp bed, drapers are lowered into the water to a depth of 0.9 meters, main engines are secured, and a bow propeller pushes the vessel, stern first, through the water. These harvesters operate like seagoing lawn mowers, pushing large cutting racks through the kelp bed, gathering the cut kelp on conveyors that carry the kelp aboard and deposit it into a bin. Modern harvesters carry as much as 550 metric tons of *Macrocystis*, which can be collected in one day of harvesting. The kelp industry in California has harvested as much as 156,000 metric tons in a single year.

Harvestability

Giant kelp is especially suitable for mechanical harvesting because: 1) the deep-water habitat allows for use of large harvesting vessels; 2) the surface canopy can be harvested several times a year without disturbing the submerged parts of the plant where vegetative and sexual reproduction occur; 3) photosynthesis, growth, and buoyancy are distributed along the entire length of the plant and, therefore, are not eliminated when the surface portion of the frond is removed; and, 4) surface canopy is regenerated by younger fronds that are growing beneath the surface.

The shallow cut and the plant's ability to regenerate quickly during good growing conditions mean that giant kelp can be harvested as many as three times each year in the most productive beds in southern California. In central California, north of Point Conception, severe winter conditions reduce the available kelp canopy, allowing only one harvest, during either summer or fall.

Annual differences in nutrient levels, water temperature, weather, and other conditions can cause substantial fluctuations in the productivity of any particular kelp bed from year to year. Accordingly, to maintain an efficient and consistent harvesting operation, it is necessary to harvest substantial kelp beds in different locations along the California coast.

The *Macrocystis* resource can be evaluated by regular aerial surveys. These surveys entail low-level flights over the kelp beds to determine abundance, condition, and harvestability. Surveyors record subjective impressions of the resource, impressions based on years of experience. Harvesting vessels are directed to the more mature areas of the resource to maximize utilization of the kelp before natural sloughing occurs.

Red abalone, Haliotis rufescens, *are harvested by commercial and sport divers throughout the kelp forests of southern California. (Photo by Ron McPeak)*

Management

Macrocystis is harvested in California from Point Loma, near San Diego, to as far north as Carmel Bay. Harvesting is managed by the California Department of Fish and Game under regulations of the State Fish and Game Commission. By State regulation, the kelp is cut no deeper than 1.2 meters beneath the surface. *Macrocystis* is harvested from kelp beds leased for a period of 20 years. No more than 25 square miles, or 50 percent of the kelp bed area (whichever is greater) within the State of California can be exclusively leased by one company. The lessee pays a minimum annual fee per area leased and a fee per ton of kelp harvested. The State of California's official kelp map indicates approximately 18,200 hectares of giant kelp canopy. Of the total 18,200 hectares, approximately 12,000 hectares (67 percent) are set aside for exclusive leasing by individual harvesting companies. In addition to leased kelp beds, some areas are designated "open" and may be harvested by any company with a kelp harvesting permit.

Other Fisheries

Kelp forests support commercial and sportfisheries within California. Sportfishing boats can generally be seen anchored near kelp forests while anglers fish for kelp bass, rockfish, and other species of nearshore fish.

Eight species of abalone occur in California and several of these prefer *Macrocystis* as a food source. These marine molluscs are harvested by commercial and sport divers throughout the kelp forests of southern California. Commercial abalone landings in California annually averaged more than 1.5 million kilograms from 1951 to 1968. In recent years, commercial landings have decreased, primarily because all virgin stocks have been picked and harvests depend on annual regrowth.

Kelp forests and rocky habitats of southern California also support a significant commercial fishery for the California spiny lobster (*Panulirus interruptus*). The species is trapped from early October through mid-March. Landings peaked in 1950 at 350,000 kilograms. In recent years, landings have averaged 157,000 kilograms, with best landings in the San Diego area. Sport divers also take considerable numbers of spiny lobster each year.

During summer months, in many of the kelp forests of southern California, there is a gill-net fishery for white seabass (*Cynoscion nobilis*), a member of the croaker family. Fishermen generally set nets in forests of *Macrocystis* and snare the large croakers as they swim through the forests.

There are three species of sea urchins common in kelp bed habitats: red, purple, and white. Purple and white sea urchins are too small to harvest commercially; only the large red sea urchin (*Strongylocentrotus franciscanus*) is harvested. Many attempts have been made to market purple and white sea urchins; presently, these species cannot be harvested and processed economically. The red sea urchin fishery in California began in 1972 and peaked in 1981 with a harvest of 9.3 million kilograms. These urchins feed primarily on drift *Macrocystis*. When ample food is available, the urchins produce good quality roe, which is shipped to Japan. The roe is sold fresh in Japan, where it is considered a delicacy.

Conservation

There are presently two programs designed to protect and enhance *Macrocystis* resources in southern California. The California Department of Fish and Game has a program entitled Sportfish Kelp Habitat Project, involving the control of sea urchins where they have over-grazed coastal areas off Palos

Verdes, near Los Angeles. Purple and white sea urchins are controlled by divers with hammers and suction dredges, while red urchins are harvested commercially. These management activities have resulted in the enhancement and protection of nearly 283 hectares of *Macrocystis* at Palos Verdes during recent years.

The second management program is being carried out by Kelco at Point Loma, near San Diego. Kelco presently employs 18 diving marine technicians and biologists who are primarily involved in controlling sea urchins at Point Loma. Hammers and suction dredges are used to control purple and white sea urchins, while red urchins are harvested by commercial divers.

The restoration or enhancement work at Point Loma actually began in 1963 with a joint effort between Kelco and Wheeler J. North and David Leighton. This restoration work has been carried on continually since 1963 and has resulted in maintenance of kelp beds as large as 730 hectares. In addition, Kelco divers transplanted a total of 35,000 juvenile kelp plants to San Diego County kelp beds from 1973 to 1976.

Management work in southern California has helped protect the unique and valuable giant kelp forests. These forests provide refuge and food for a variety of animals, fishing and diving areas for commercial and sportfishermen, and raw material for the extraction of the increasingly commercially significant algin.

Ron H. McPeak is a senior marine biologist with the Kelco company in San Diego. Dale Glantz also works at Kelco, as an associate marine biologist.

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Salmon Ranching:
A Growing Industry in the North Pacific

by William J. McNeil

Photo courtesy of U.S. Fish and Wildlife Service

Relatively few people have had reason to visit Disappearance Creek, a small chum salmon spawning stream in the Alaska wilderness. However, there were visitors in 1979 and again in 1980. Their mission was to acquire chum salmon eggs for a new salmon ranch operated by Southern Southeast Alaska Aquaculture Association, Inc. (SSAAA). The Alaska Department of Fish and Game had given SSAAA permission to use Disappearance Creek chum salmon as a donor stock.

SSAAA had an operational hatchery at Whitman Lake near Ketchikan in 1979, but the transplantation of chum from Disappearance Creek was intended for a hatchery not yet built. The new hatchery was scheduled for construction in 1983 at Neets Bay, north of Ketchikan. Because chum salmon mature in four years, it was decided to hatch eggs collected from Disappearance Creek at the Whitman Lake hatchery and transfer the fry to pens floating in salt water at Neets Bay. The juveniles were to be fed in the pens for about two months and released into Neets Bay. The hope was to have a run of chum salmon returning to Neets Bay in 1983 when the new hatchery would be ready to receive them.

Disappearance Creek and Neets Bay are both about 50 kilometers from the Whitman Lake Hatchery, but they lie in different directions (Figure 1). Two transplantations were involved—donor stream to hatchery and hatchery to release site. A wild stock (eggs) was displaced to artificial-hatchery and pen environments. Fingerlings were released from saltwater pens rather than into a freshwater stream. These operations were quite different from

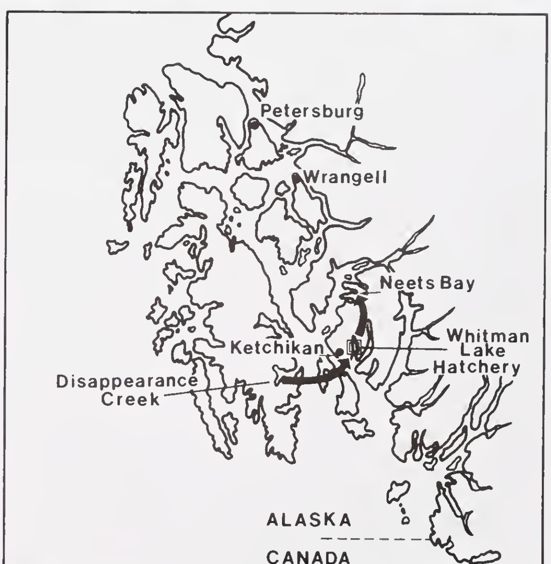

Figure 1. Wild chum from Disappearance Creek were raised at Whitman Lake hatchery and released into Neets Bay.

what the fish experience in nature; there was ample reason to doubt the eventual success of the project.

Donald Amend, Operations Manager for SSAAA, described the 1983 return of chum salmon to Neets Bay as follows: "We had no preliminary information on how many (adults) would actually return, but by mid-September numerous fish were evident in the Bay. The fish ladder and holding pond were finally opened on 23 September, and fish immediately started entering the facility. For the next 15 days straight, our hatchery crew worked from dawn until past dark every day. When the water finally calmed, we had taken 28.6 million eggs and had handled 48,511 fish, nearly twice what we had expected."

Encouraging preliminary results with the Neets Bay chum salmon ranching project (Figures 2 and 3) have important implications for salmon ranching in Alaska and elsewhere. They reinforce other experiences: salmon ranching offers promise of economic success. The encouraging results with transplanted fish released as juveniles from a saltwater release facility strengthens the foundation for innovative technologies. Neets Bay is also further evidence that institutional structures for growing and harvesting salmon are in transition.

The chum salmon that returned to Neets Bay in 1983 became the property of a private corporation once they entered a special harvest area. Prior to 1972, proprietary harvest of salmon was prohibited by the Alaska Constitution, but in that year, a constitutional amendment authorizing limited entry for fisheries and aquaculture was approved by Alaska citizens. This was followed by a series of laws, initiated in 1974, that enabled private nonprofit hatchery corporations to ranch salmon in Alaska. SSAAA is one of 20 private nonprofit corporations to receive a permit from the state to ranch salmon. By 1983, 17 Alaska corporations were actively involved with ranching operations.

History

Pacific salmon have been raised in hatcheries since 1872. California, Oregon, Washington, Alaska, British Columbia, and Japan had salmon hatcheries before the turn of the century. Interest in hatcheries waned during the 1930s and 1940s because of technical and economic problems. It was not until the 1950s that hatcheries began to make sustained progress.

Japan, the Soviet Union, and the Pacific Northwest led the development of salmon-hatchery programs after World War II. Alaska and British Columbia are the most recent entrants in a rapidly emerging international effort to ranch salmon. Industrial-scale salmon ranching has become important throughout the North Pacific rim. Release of juvenile salmon from hatcheries has been doubling in recent decades, and this trend is expected to continue (Figure 4).

Statistics for numbers of juveniles released from hatcheries and their recapture rates suggest that 25 to 30 percent of the salmon biomass harvested from the North Pacific Ocean currently originates from hatcheries. In certain geographic areas (including the Japanese coastal fisheries), more than 90 percent of harvested salmon originate in hatcheries.

Government Regulation

The Japanese have a progressive, well-established salmon-ranching industry. They presently harvest 20 to 30 million ranched chum salmon annually, roughly equivalent to 50 to 60 percent of the Alaska salmon fishery (based on the total weight of harvested fish). Their goal is to boost production to nearly 40 million adult salmon annually. The cost of producing juvenile chum salmon in hatcheries is low, since they are released into the ocean at a small size (typically about 1 gram). The return rate of surviving adults to Japanese coastal fisheries has shown steady improvement (Figure 5). Every kilogram of juveniles released from hatcheries generates about 80 kilograms of adults.

Institutional structures for producing and harvesting salmon vary greatly among political jurisdictions. Salmon are public property while in the ocean. They typically cross political boundaries on feeding migrations. Rights to harvest salmon are dictated by governments and international treaty organizations. These rights vary depending on location. Where salmon occur within 320 kilometers of a coastline, harvest is usually controlled by the nearest coastal sovereignty. When beyond 320 kilometers, international treaties usually govern rights to salmon.

Some sovereignties allow common property fisheries on salmon, while others do not. The Japanese and Soviet governments lease fishing rights to private and state-owned organizations, while the Canadian national and United States federal and state governments license individuals to compete for fish in public waters. Alaska, Oregon, and California also license private corporations to harvest fish returning to their hatcheries.

The structures of institutions engaged in salmon ranching vary considerably among governments. Japan and the United States have hatcheries operated by a mixture of private organizations, prefectural (state) governments, and central governments. In Japan, the central government owns and allocates eggs for hatchery propagation and thereby exercises control over all production. In the United States, eggs are largely controlled by state governments. The Soviet Union authorizes state-owned corporations to ranch salmon. Only the national government ranches salmon in Canada.

Economics

There have been many demonstrations of the technical feasibility of salmon ranching, but success eventually must be measured according to economic benefits. Two essential determinants of economic benefits are 1) cost efficiency and 2) cost distribution. Cost efficiency relates to productivity. The cost of generating an adult for harvest is the ultimate criterion for evaluating cost efficiency. Best results to date probably have been obtained in Japan with chum salmon.

Figure 2. Hatchery under construction at Neets Bay, Alaska, 1983. (Photo by Rollo Pool).

Figure 3. Adult chum salmon collected for spawning at Neets Bay, Alaska, 1983. (Photo by Rollo Pool).

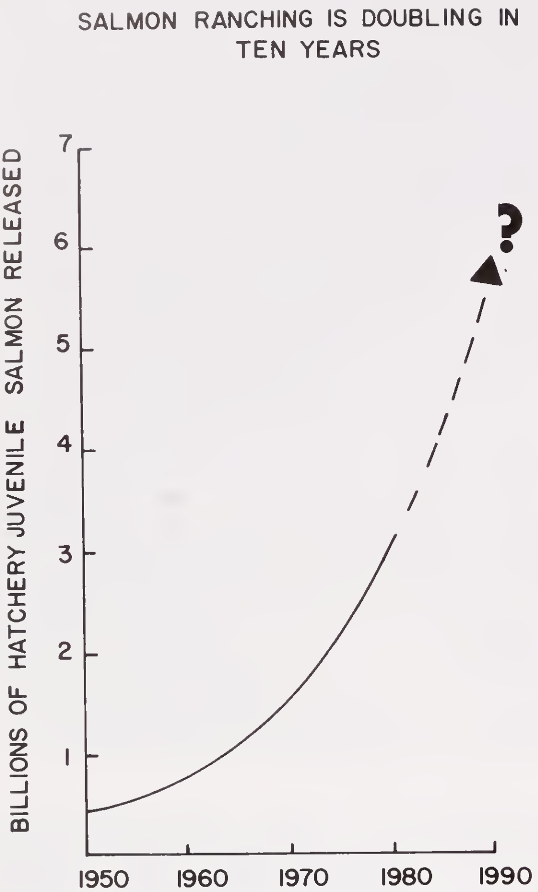

Figure 4. Trend of release of juvenile salmon into the North Pacific Ocean. All species are combined for all countries.

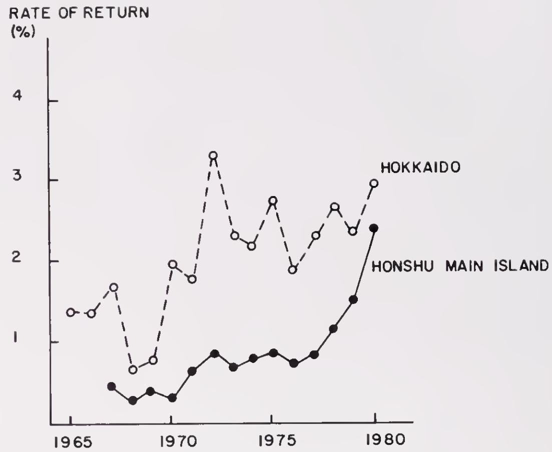

Figure 5. Marine survival of juvenile chum salmon released from Japanese hatcheries on Honshu and Hokkaido Islands.

Cost distribution addresses the questions Who pays? and Who benefits? Many public salmon-ranching programs in the United States and Canada place the burden of cost on taxpayers in general, whereas benefits flow to those who participate in common-property fisheries. Hatcheries operated by private corporations are phasing into production in Alaska, Oregon, and California. These private hatcheries have little or no reliance on public subsidy. In Alaska, the cost of operating private hatcheries is shared by commercial fishermen through a severance tax collected by the state and distributed to private hatcheries that operate as nonprofit corporations. In Oregon and California, the main source of income for private hatcheries comes from sale of fish returning to ranching facilities. Alaska's private hatcheries also generate income by this means.

Salmon ranching represents a visible step in a transition from a hunting to a farming economy in the oceans. Industrial-scale ranching is limited primarily to the North Pacific Ocean at present, but pilot-scale projects are beginning in the North Atlantic and South Pacific oceans.

The growing interest in salmon ranching has been a stimulant to the development and implementation of new and improved technologies. Bacterins and vaccines for control of diseases are recent developments. Diets are being improved. Innovative systems for growing juvenile salmon are being applied under a variety of environmental conditions. The floating, vertical raceway (Figure 6) is an example of an innovation adapted to remote sites in Alaska where the cost of constructing facilities on land is prohibitively high.

Sophisticated environmental-control systems have significantly increased production of salmon juveniles. Water at the Oregon Aqua-Foods, Inc., hatchery at Springfield, Oregon, for example, is disinfected, warmed in the winter, and oxygenated in the spring and summer (Figures 7 and 8). These environmental controls have contributed to production levels about three times higher than typical hatchery production.

Growing juvenile salmon that are ready to enter the sea is an ongoing effort of salmon ranchers. Experience shows, however, that the sea is not always ready to accommodate the juveniles. As in agriculture, crop failures caused by uncontrolled environmental variables are common.

Figure 6. Vertical raceway hoisted from its flotation collar (left center). (Photo courtesy of NMFS, LPW, Alaska).

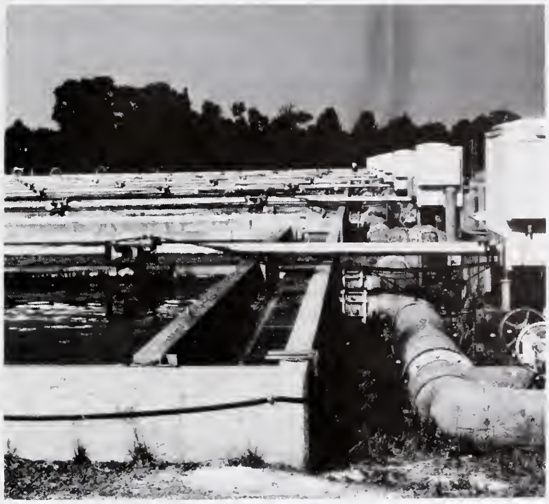

Figure 7. Automated systems are used to feed juvenile salmon at the Oregon Aqua-Foods, Inc., hatchery at Springfield, Oregon.

Figure 8. Water disinfection and oxygenation systems at the Oregon Aqua-Foods, Springfield, Oregon hatchery have contributed to high production of juvenile salmon.

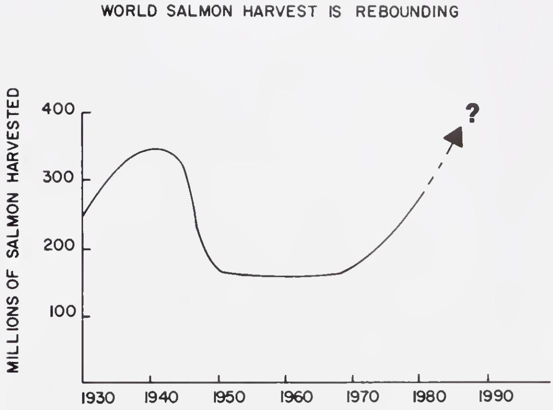

Figure 9. Trends in world harvest of salmon.

The Pacific Northwest is currently experiencing a salmon crop failure. The 1983 return of salmon to the coasts of California, Oregon, and Washington was the worst in decades. The outlook for 1984 remains dismal. The problem is caused by an environmental event, El Niño, which has resulted in the replacement of cold waters off the Pacific Northwest coast with warm waters from the tropics. Oceanographers warn that the water has been warming in the northeast Pacific Ocean since 1976. The 1983 El Niño resulted in an exceptionally strong northward surge of warm water. A variable environment resulting in periodic crop failures is a risk that salmon ranchers share with terrestrial farmers.

Salmon ranching faces other uncertainties. Some are ecological. Some are technological. Some are sociological. Progress is being made, nevertheless. The increasing supply of salmon (Figure 9) attests to this. Salmon ranching should become an increasingly important contributor to the world supply of salmon, which may soon exceed historic high levels.

William J. McNeil has worked with salmon for three decades. He has held teaching and research assignments at the University of Washington, Oregon State University, and the University of Alaska. He also has held assignments in Alaska with the National Marine Fisheries Service and the Governor's Office. He currently serves as General Manager of Oregon Aqua-Foods, Inc., a subsidiary of the Weyerhaeuser Company.

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The Development of the Ocean

by Geoffrey K. Morrison

New England's oceanographic industry evolved around the two largest centers of oceanographic research there, the Massachusetts Institute of Technology (MIT) and the Woods Hole Oceanographic Institution (WHOI). The relative newness of oceanographic science explains why many of the founders of companies formed to provide instrumentation for oceanography are still active in their organizations today. It is not possible to mention all of these companies; many are located on Cape Cod and their founders well known to New England readers.

Emeritus Professor Harold "Doc" Edgerton of MIT, during the early 1940s, helped found the Waltham, Mass., firm of Edgerton, Germershausen, and Greer (now known as EG&G). He was probably one of the first men to build commercial instruments for use in the ocean. Having perfected a high-speed photographic technique using stroboscopic lights in the laboratory to enable the camera to "freeze" events, such as a bullet penetrating an apple, Edgerton went on to tackle the task of putting his camera and light source into a waterproof box that could be lowered through the water to take photographs of the ocean floor. One problem he had with this work was persuading scientists who had never seen the ocean floor that it might be worth giving up a valuable berth on a research vessel to an engineer in order to view it.

One of his first photographs revealed a rocky outcrop—exciting marine geologists and guaranteeing a future for the Edgerton Camera and EG&G as an oceanographic company. The next product developed by EG&G was an acoustic, television-like device with which sound waves bouncing off the ocean floor are used to draw pictures of bottom topography: side-scan sonar.

The early 1960s saw a rash of entrepreneurial activity in the ocean-instrumentation industry. Neil Brown, an Australian engineer who had collaborated with Bruce Hamon at the Commonwealth Scientific and Industrial Research Organization in Sydney, Australia, in the design of an electronic instrument for analyzing the salt content of deep-sea water samples (salinometer), was persuaded to join the Hytech Company in San Diego. Brown developed an in-situ instrument to make continuous profiles of salt content and temperature-versus-pressure in the ocean.

Martin Klein left EG&G to form Klein Associates in Salem, New Hampshire, specializing in a side-scan sonar device. Samuel Raymond left EG&G to form the Benthos Company, manufacturing temperature and depth recorders. Both men were encouraged by their employer, Doc Edgerton, in their pursuits. David Frantz, an MIT mechanical engineer and 10-year employee of WHOI, and his long-time friend, Albert Wilson, a marketing executive, formed Ocean Research Equipment (O.R.E.), on Martha's Vineyard, specializing in underwater acoustics.

A former member of the WHOI scientific staff, Paul Ferris-Smith, then at the Marine Biological Laboratory (MBL), teamed up with Alex Dingee, an entrepreneur, and Fred Feyling, an engineer, to form the Geodyne Corporation. Bill Richardson, who invented a digital film-recording rotor current meter while working at WHOI, contracted with Geodyne to manufacture this instrument. In Marion, Mass., the Braincon company was formed by Ted Brainard and Courtland B. Converse, to manufacture a film-recording current meter in direct competition with Geodyne, benefiting the scientific user community.

By the mid-1960s, small oceanographic instrumentation companies were numerous. Even some of the large aerospace industries were starting to become interested. In short, competition was fierce and the oceanographic industry was entering what was to become a five-year high. In the early 1970s, however, ocean research paused and many an entrepreneur's heart missed a beat until the oil shortages hit in 1974 and offshore exploration for oil became a big industry, causing many small oceanographic instrumentation companies to modify their orientation and start courting oil companies at their offices in Houston.

In 1969, foreseeing a requirement for finer-scale microstructure (vertical scales smaller than one meter), in-situ measurement of ocean salinity and temperature, Neil Brown left Hytech (which had become Bisset Berman and was then Plessey) and, with funding from the Office of Naval Research (ONR), commenced work at WHOI to develop a new high-resolution salinity and temperature profiler. By 1971, the design was complete and preliminary trials had been successful. Within the next three years many ocean-research organizations were requesting copies of the new instrument and Neil Brown Instrument Systems, Inc., was born. Earlier, Richardson had suggested the formation of an instrument-manufacturing division at WHOI, but it was felt that the Institution's nonprofit status barred profit-center organization.

Neil Brown Instrument Systems grew rapidly, and with the assistance of grants from ONR and the National Data Buoy Office developed a solid-state acoustic current meter. The design for a self-balancing bridge to accurately measure temperature followed.

Benthos diversified, forming the Tap Tone

raphic Industry in New England

Conductivity and depth profiler (CDT) mounted (top, front) on Anderson Research Laboratory's submarine, Makali'i. Data are recorded on audio tape inside the vehicle for subsequent analysis.

division to manufacture an acoustic device to detect flaws in the food-canning process. The oceanographic division developed an unmanned submersible. O.R.E. expanded their interests, acquired a boat yard, and developed an acoustic flow-measuring device. In 1982, they became part of the British Ferranti Group.

Two other companies in the United States, Inter Ocean Systems in San Diego, Calif., and Datasonics in Cataumet, Mass., were formed by previous employees of O.R.E. To assist in overseas sales, O.R.E. set up three subsidiaries in Europe. The Braincon and Geodyne companies are no longer in existence, but their principals are still active. The Braincon name was bought by General Time during acquisition. Braincon's product line was later sold to one of the founders, but the name was lost. Ed Brainard reorganized and renamed the former Braincon company; it operates today as Endeco. Geodyne was acquired by EG&G, as a separate division. As other companies were acquired, Geodyne was merged into the Environmental Equipment Division of EG&G making, *inter alia*, Geodyne instruments. This division later spawned EG&G's Environmental Consultants Division. Each of these companies at one time had their offices in Woods Hole.

In the early 1980s, several factors began to impinge on the United States oceanographic marketplace. The equipment requirements of the small number of research organizations approached saturation levels. A new, albeit temporary, oil glut reduced activity in offshore exploration with a corresponding reduction in the demand for oceanographic/geophysical equipment. The government, which had generously funded pure oceanographic research, developed a new sense of fiscal responsibility and decided to spend a larger percentage of the discretionary budget on defense. Finally, the very strong export market for

oceanographic products was adversely affected by a strong U. S. dollar, which caused a rise in the price of all U. S. products overseas, in the range of 10 to 30 percent.

The response of many oceanographic businesses to this new economic climate was diversification. Neil Brown Instrument Systems redesigned their instruments to produce more compact systems: equally reliable, but less expensive. The second industry-wide response called for is a reduction of marketing/selling expenses by combining complementary companies' sales efforts to effect cost savings. Such a strategy is currently being undertaken by Neil Brown Instrument Systems and Ferranti O.R.E. The future may involve development of overseas manufacturing capability to utilize less expensive labor and to bring service closer to substantial overseas customer bases.

The transition from rapid growth to entrenchment has certainly changed the attitudes and outlooks of this largely entrepreneurial business. All in this industry look to the future with one certain thought: whatever it becomes, it will never be boring.

Geoffrey Morrison is a British citizen, born in Plymouth, England, living in the United States since 1975. He is Vice President of Sales for Neil Brown Instrument Systems, Inc.

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1A. TITLE OF PUBLICATION: Oceanus
1B. PUBLICATION NO.: 0 0 2 9 8 1 8 2
2. DATE OF FILING: Sept 28, 1983
3. FREQUENCY OF ISSUE: Quarterly
3A. NO. OF ISSUES PUBLISHED ANNUALLY: 4
3B. ANNUAL SUBSCRIPTION PRICE: $20
4. COMPLETE MAILING ADDRESS OF KNOWN OFFICE OF PUBLICATION *(Street, City, County, State and ZIP Code) (Not printers)*: Woods Hole Oceanographic Institution, Water St., Woods Hole, MA 02543
5. COMPLETE MAILING ADDRESS OF THE HEADQUARTERS OF GENERAL BUSINESS OFFICES OF THE PUBLISHER *(Not printer)*: (Same as above)
6. FULL NAMES AND COMPLETE MAILING ADDRESS OF PUBLISHER, EDITOR, AND MANAGING EDITOR *(This item MUST NOT be blank)*
PUBLISHER *(Name and Complete Mailing Address)*: Woods Hole Oceanographic Institution (nonprofit organization)
EDITOR *(Name and Complete Mailing Address)*: Paul R. Ryan, Oceanus magazine, WHOI, Woods Hole, MA 02543
MANAGING EDITOR *(Name and Complete Mailing Address)*: (None)
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Surimi Gel and the U.S. Seafood Industry

by Chong M. Lee

During the last decade in the United States, few advances were made in processed-seafood technology, mostly because of a lack of innovation coupled with limited technical expertise. Most standard commercial practices have been adopted from other nations' industries. Although the processed-seafood industry has expanded in recent years, products are limited to breaded and frozen products. This limited growth is apparent in the small percentage of total prepared-food commodities represented by seafood-related items.

Recently, there has been increased interest in developing less labor-intensive processed-seafood products—primarily fabricated products—which bring a higher profit margin than fresh-fish products. The market for these fabricated products is also less competitive, and fabrication allows for flexibility in formulation to meet specific physical and nutritional requirements. This, in turn, makes possible a greater variety of quality products.

However, since the introduction of Japanese surimi-based products into U.S. markets, the entire structure of the fabricated-seafood market has changed. As a result of the high level of consumer acceptance of fabricated products, the market share has grown at a rate faster than anticipated: from 2 million pounds sold in 1979 to 29 million pounds in 1983.

The concensus among U.S. seafood processors that the seafood industry should expand their efforts in fabrication is based on a variety of goals: 1) to reduce the nondomestic dominance of the $60 million surimi market; 2) to stimulate use of underutilized fish species and related waste products; 3) to introduce new products with high profit margins; and, 4) to provide versatility in product lines. Consequently, the National Marine Fisheries Service (NMFS) designated $1.5 million in Saltonstall-Kennedy funds to be spent on the development of the U.S. surimi industry.

What is Surimi?

Surimi is a Japanese term for mechanically deboned fish flesh that has been washed with water. Minced fish also is a mechanically separated flesh, but is not washed. Washing not only removes undesirable matters (such as blood, pigments, and odorous substances), but, more importantly, it increases the concentration of functional protein (actomyosin). This gives the substance the elasticity essential to surimi-based products.

For more than 20 years, food scientists have attempted to develop products with soybeans that simulate such natural products as meat and shellfish. They have not been able to produce textures or flavors that are acceptable, except in a few cases, such as imitation bacon bits. Soybeans have been added more successfully to various processed-food products as extenders.

Surimi gel may offer what soybeans do not. Because of its high concentration of myofibrillar protein, surimi, unlike soy protein, produces an elastic and chewy texture that resembles that of shellfish. Taking advantage of this unique property, the Japanese have used surimi extensively for more than a century to develop a variety of fabricated products. The Japanese surimi technology led to the development of commercially acceptable shellfish analogs that would have failed in the U.S. market had soy protein been used.

Producing Surimi

Surimi is produced by repeatedly washing mechanically separated fish flesh with chilled water (5 to 10 degrees Celsius) until it is both odorless and colorless. In a batch process, at least five wash cycles are required. The number of wash cycles and the volume of water varies with the fish species, the initial condition of the fish, the type of washing unit, and desired quality of surimi. On the other hand, in a commercial process, the washing is done in a series of tanks and rinsing units (Figure 1).

During repeated washings, much of the water-soluble sarcoplasmic protein is removed, together with undesirable blood pigments, fat, odorous substances, and enzymes, while the level of myofibrillar protein (actomyosin) increases. The level of functional actomyosin is a measure of the

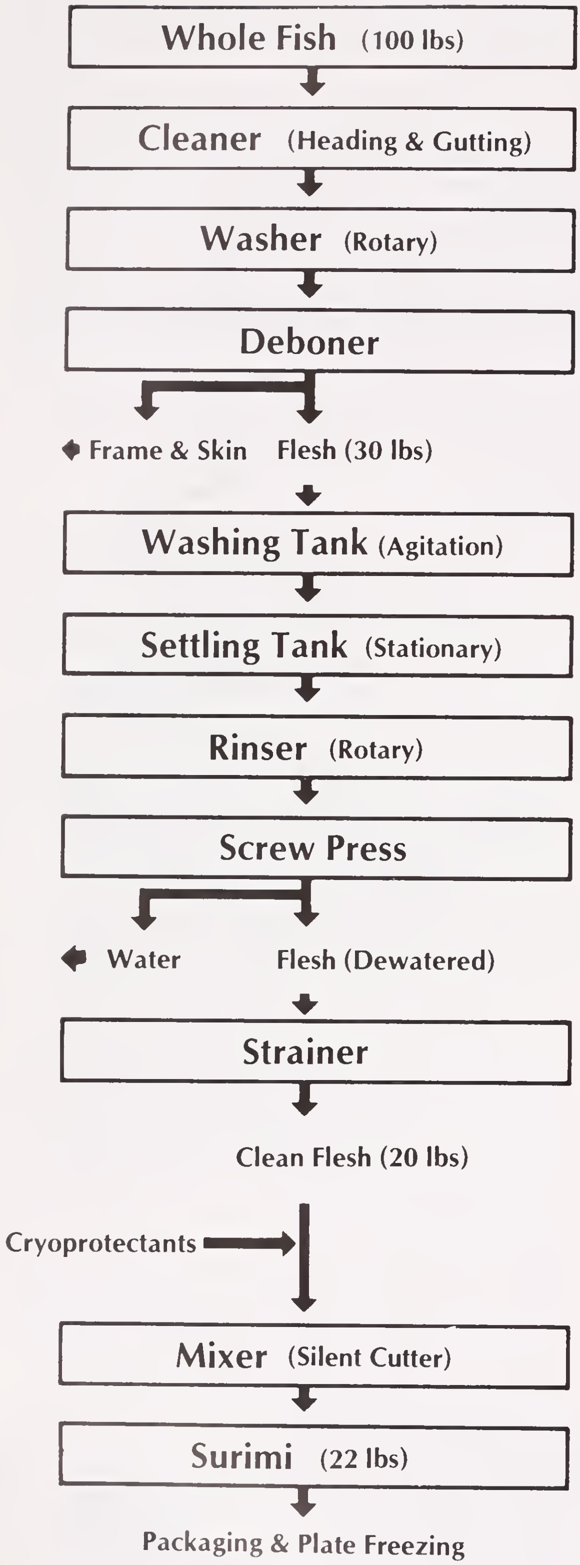

Figure 1. Commercial scale of surimi manufacturing.

usefulness of the surimi. This explains why surimi gives a more elastic texture than minced fish flesh that has not been washed.

The washings are followed by dewatering with the aid of a screw press. The resulting fish flesh is transferred to a strainer in which all remaining bone and scale residues are removed. At this point, the flesh is white, odorless, and residue-free. Using a silent cutter, cryoprotectants—namely, sugar, sorbitol, and polyphosphates—are mixed into the fish flesh at levels of 4 percent, 4 percent, and 0.2 percent, respectively. The addition of cryoprotectants virtually guarantees that the frozen product will not lose its essential properties for a year, critical for making high-quality surimi gels.

Surimi-based products are produced through extrusion of the surimi sol into various shapes. The closer the simulation to be achieved, the greater the sophistication of extrusion technique required.

There are two principal extrusion techniques. The first involves extruding or molding the paste into the desired shape and allowing it to set and form an elastic gel. Restructured-shrimp products belong to this category and have been on the market for quite some time. The second technique involves extruding the paste into a thin sheet through a series of rollers. The extruded sheet is then partially heat set and cut into strips of a desired width. The surimi used in this process must be of high quality so that the paste remains cohesive and elastic while being extruded through the series of rollers. The width of the strips determines the type of finished products. Fine strips are preferred for the fiberized crab legs, whereas wider strips are more appropriate for scallops or seaflakes. After the stripping, the individual strips are bundled into the form of a texturized product (Figure 2).

Impediments and Resources

The key impediments to U.S. production of surimi-based products are the lack of consistent domestic surimi production to ensure a stable supply of the base material and the lack of technical support for quality control and development. Naturally, questions arise as to how feasible it is to produce surimi domestically and whether or not we have sufficient resources and technical expertise to produce a commercial quantity at a profit.

As for resource availability, Alaskan pollock is presently a major source for commercial surimi production. The stock yield of Alaskan pollock is expected to be as high as 3.6 billion pounds annually. Most are caught by Japanese and Korean fishermen and processed into surimi on board. Several other regionally underutilized species have been studied for suitability in surimi production by researchers at the University of Rhode Island and North Carolina State University. The results of these studies indicate that all hake species can be effectively utilized for surimi production. In addition, a recent experiment at the University of Rhode Island revealed that the frame waste from ground fish (including cod, haddock, and Atlantic pollock) is a potential source of surimi.

Frame wastes are presently ground up and sold as a base for pet foods. A feasibility study to

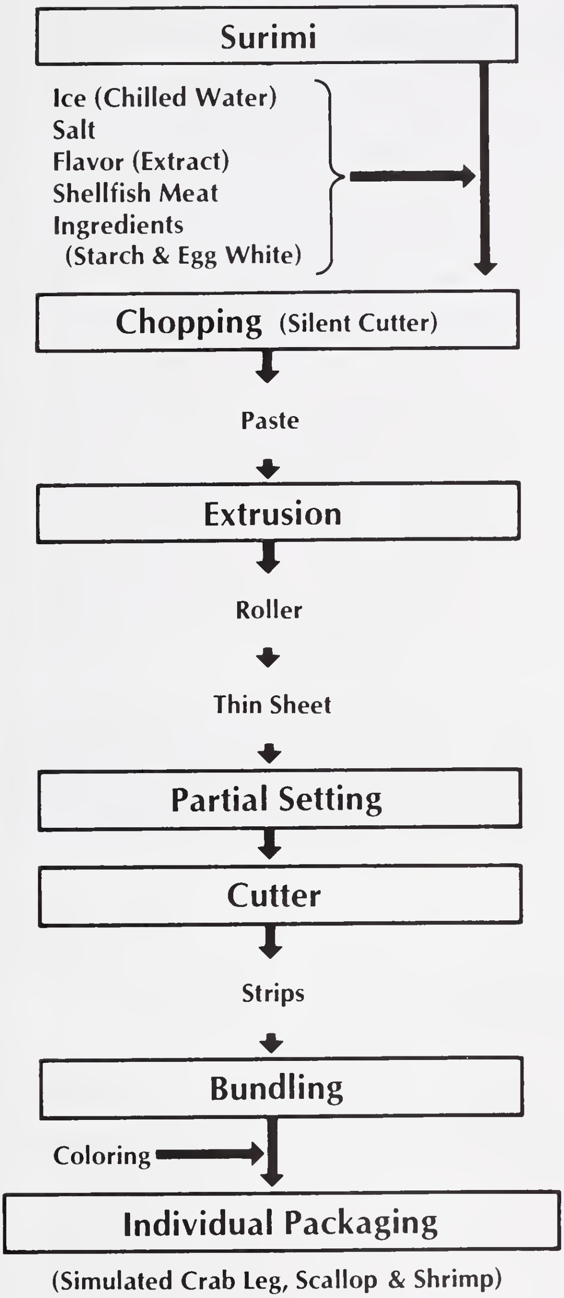

Figure 2. Processing scheme of surimi-based products.

determine the suitability of other industrial fish species for surimi production is underway at North Carolina State University. The species being considered are menhaden, freshwater catfish, and gulf croaker.

On the basis of average U.S. commercial landings from 1977 through 1981, the potential yields from frame waste are estimated as 48 million pounds from Atlantic cod, 22 million from haddock, 16 million from hake, and 18 million from pollock. This total of 104 million pounds would yield about 40 million pounds of surimi. In addition, the potential yield of surimi from whole hakes could reach 7 million pounds, based on landings of 30 million pounds. This clearly indicates that there is an ample supply of raw material for surimi production.

In the United States, surimi technology has stagnated since it was introduced. Lack of technical knowledge is believed to be the main cause of this slow advancement, particularly in the following areas: economics of surimi manufacturing; how variations in the surimi process affect the gel characteristics of finished products; the production of natural shellfish flavor; and, the development of the fabrication machineries used for surimi-based products.

The Market Outlook

According to NMFS statistics based on the volume of imports, the annual growth of surimi-based products in the United States is exponential (Figure 3). Given that surimi products are in the introductory stage, the rapid rate of growth, and the fact that there is no sign of saturation of the market, one can project that the market for surimi-based products will be large, as long as quality continues to improve.

Presently, U.S. surimi technology lags far behind Japanese technology, which enables the Japanese to dominate the world market with their highly-automated production system (Figure 4). Because the United States is the world leader in food fabrication, major technological breakthroughs are expected within a couple of years in the areas of texturization, flavor, and machine automation. This should offset Japan's technological advantage and eventually put the United States in a competitive position. If the world market expands as rapidly as the domestic market, there will be plenty of export opportunities for all producers provided that price and quality remain competitive.

According to a recent consumer survey compiled by E. W. Leonard at Emory University, flavor, texture, and appearance must be improved for successful development of surimi-based products. The flavor should be subtle and well-rounded (natural), not harsh or obviously artificial. The texture should be intermediately firm and elastic (neither soft/mushy nor tough/rubbery) with no spongy texture. The mouth feel should closely resemble that of the product being simulated. The appearance should be appetizing, avoiding excessive uniformity in color and internal structure. The visual texture—particularly the inside of the product—should resemble the natural counterpart. Coloring should be subtle and variegated.

U.S. Research

Most U.S. industrial-development projects in the Saltonstall-Kennedy program operate under the auspices of the Alaska Fisheries Development Foundation (AFDF), because of its access to the pollock resource. The prime mission of AFDF is to familiarize the U.S. food industry with surimi by distributing the raw product to interested food companies. AFDF also will help a U.S. seafood firm establish a surimi production plant by supplying the

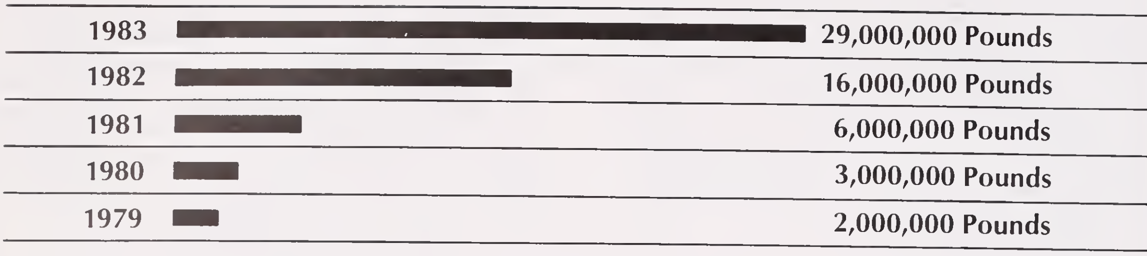

Figure 3. U.S. surimi imports. (National Marine Fisheries Service, 1983)

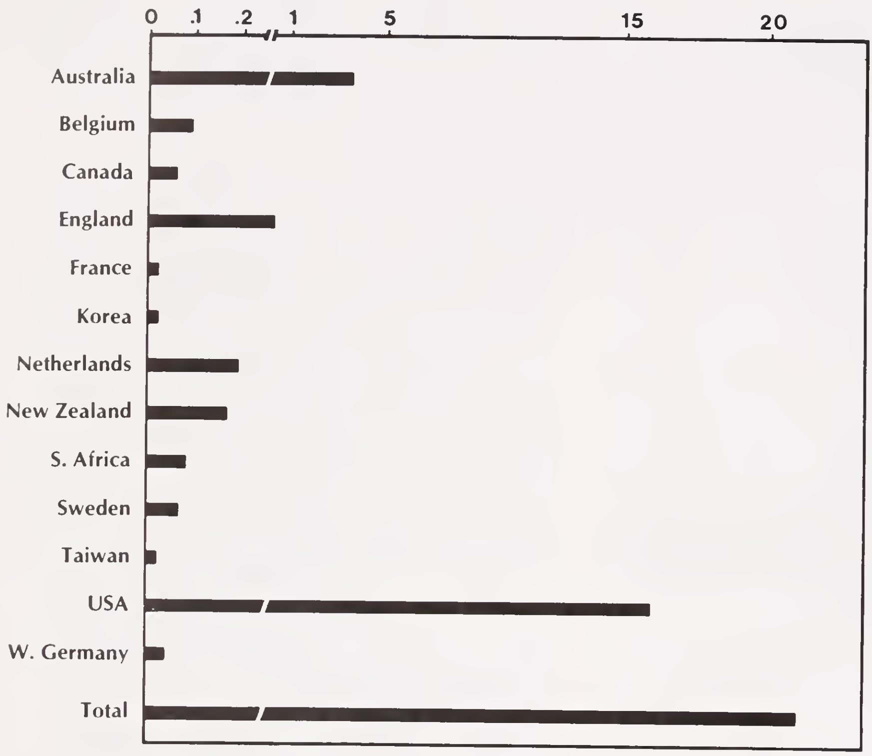

Figure 4. Export totals (millions of pounds) for surimi-based products from Japan from January through October 1982. Jagged line denotes change in scale. (Thrash and Akahane, 1983)

equipment in exchange for the finished product. AFDF is working with other regional foundations on marketing and surimi specification programs.

On the East Coast, the New England Fisheries Development Foundation is investigating the economic feasibility of producing surimi from red hake. Other NMFS and Foundation projects deal with consumer and trade attitudes toward surimi-based products, a labeling strategy, product standards, and identification of potential markets.

Under the same program, the University of Rhode Island sponsors a surimi project in collaboration with the Gloucester Fisheries Lab in Massachusetts and the New England Fisheries Development Foundation. The project's aims include optimization of the surimi-manufacturing process based on the regionally available, underutilized whole fish and frame waste; assessment of the effect of various processes and ingredients on surimi-gel properties; and determination of the economic feasibility of blending surimi of different species. Five regional seafood companies are participating in this development project.

Researchers at the University of Rhode Island also are developing effective methods for the recovery of flavor and meat from shellfish waste, with sponsorship from Sea Grant and the region's seafood industries. At North Carolina State University, investigations into new species suitable for surimi production from among those available in the southeast and Gulf coasts is under way, as is work on surimi-gel characterization and product standards.

Chong M. Lee is an associate professor in the Department of Food Science and Nutrition at the University of Rhode Island, Kingston. He is a principal investigator of the Saltonstall-Kennedy and Sea Grant projects concerning surimi process optimization, product formulation, flavor and meat recovery, and seafood fabrication by freeze-contraction and flaking techniques.

Acknowledgments

The author acknowledges the support of the National Marine Fisheries Service and the Office of Sea Grant, NOAA, Department of Commerce, under Grant No. NA84EM-D-00003 and NA81AA-D-00073, and Champlin Seafoods and Stonington Seafoods, Point Judith, Rhode Island.

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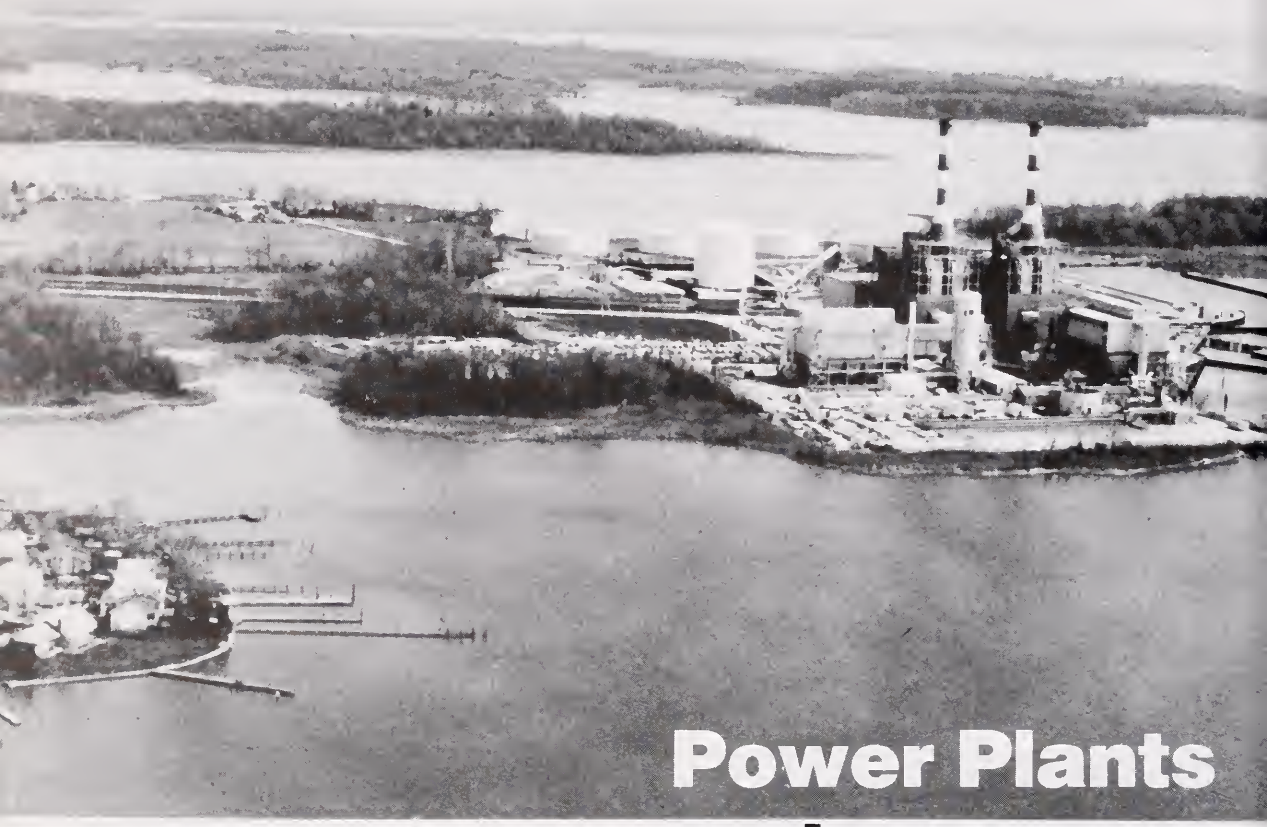


Charles P. Crane Power Plant: 400-megawatt, coal-fired plant selected as hatchery site.

Power Plants and Striped Bass: *A Partnership*

by Elizabeth I. Bauereis

and John N. Kraeuter

AQUACULTURE
PROJECT
Baltimore Gas & Electric
C.P. Crane Plant

Baltimore Gas and Electric Company (BG&E) supplies more than 2 million residents of central Maryland with electricity, gas, and steam. Concerned with the preservation of our Cheasapeake Bay community's resources, BG&E sponsors several projects designed to utilize waste by-products of energy production.

Fly ash—a by-product of coal combustion—is removed from the flue gas streams at our plants and used as structural fill. A BG&E subsidiary is using this fill to convert marginal real-estate properties into prime business-park sites. A recovery plant under

EDITOR'S NOTE: The Chesapeake Bay spawning grounds account for about 90 percent of the striped bass that migrate along the coast from North Carolina to New England. Rhode Island recently adopted a three-year moratorium on all fishing for stripers and Maryland is considering a similar move. The Atlantic States Marine Fisheries Council voted unanimously in December, 1983, for a 55-percent reduction in the present commercial harvest of stripers. A 50-percent reduction in the harvest is figured to increase the number of eggs sixfold. A threefold increase is necessary to maintain current population levels of the species. According to one Rhode Island report, 30 percent of all stripers caught last year were 12 years old. One fisheries scientist in Woods Hole commented that stripers would be lost as a useable resource unless something is done to alleviate pressure on the species. "There is no hope in sight for recovery," he commented. Perhaps the project described in this article offers some hope for this splendid species.

construction at the Back River Waste Treatment Plant will extract pure methane from raw sewage gas; pumped through BG&E's natural-gas pipeline, the recovered methane will annually meet the energy needs of 2,500 residential gas customers.

Above, striped bass fisherman casts into surf at Martha's Vineyard. At right, record-breaking striper caught on the Vineyard. (Photos by Mark Lovewell).

The proposal of an aquaculture system that would use waste heat at power plants in the form of hot water to raise striped bass fingerlings represented an opportunity for the company to use a waste product and begin replenishing the environment. In 1981, BG&E began to explore the feasibility of such a project.

Siting an Aquaculture Facility

The most promising BG&E sites for the aquaculture project were the Calvert Cliffs Nuclear Power Plant and the Charles P. Crane Power Plant. The Calvert Cliffs Nuclear Power Plant (CCNPP) is situated in southern Maryland on the mesohaline portion (5 to 15 parts-per-thousand salinity) of the Chesapeake Bay. In 1981, it accounted for more than 56 percent of the electric power generated in our service territory. CCNPP seemed a good candidate for waste-heat aquaculture because it meets the need for a steady supply of heated discharge water. The higher a power plant's capacity factor (the frequency of electric generation), the better its potential for waste-heat aquaculture.

Basically, a power plant operates by using energy to fire boilers that make steam to drive the plant's turbines. The steam is run through a condenser where it is cooled to a liquid state. The condenser itself is then cooled with additional water, creating waste hot water. The resulting temperature change (ΔT) expresses the amount of heat added to the cooling water by the condenser.

The disadvantages of the CCNPP as a site for waste-heat aquaculture became apparent. The plant's ΔT is marginal at 10 to 12 degrees Fahrenheit: heat exchangers would have to be used to transfer the heat energy from the nuclear power plant's waste hot water (which cannot be used as a unique habitat for fish) to other water; this would inevitably cause some loss of heat energy, probably to a level below that needed for this project.

Second, the CCNPP is built into a cliff; the property at water level suitable for an aquaculture facility is very limited. Pumping all the water to the top of the cliff to overcome this problem would be prohibitively expensive. Third, the salinity in this portion of the Chesapeake Bay is intolerably high for striped bass in early stages of growth.

The other power plants of the BG&E system with sufficiently high capacity factors situated in areas with appropriate salinity for young striped bass were carefully evaluated. The power plants located in Baltimore Harbor were not considered appropriate. Although water quality in the harbor has improved considerably in the last 10 years, the need for debris-removal and filtration systems there would make the project far too costly and complicated.

Ultimately, the Charles P. Crane Power Plant in the northeastern corner of Baltimore County was chosen as the best available site for a striped bass waste-heat aquaculture facility. The salinity level of the water is appropriate for raising striped bass; the water quality appeared good (based on several years of impact studies). The capacity factor of the plant seemed adequate since the plant was being converted from oil to coal and the amount of waste heat available (ΔT for the plant is 14 degrees Fahrenheit above ambient water temperatures) was promising. Further study disclosed a small plot of land on the discharge canal that could be used for a hatchery site. Although small, this site is suitable because it has easy access to both heated discharge water and bay water. This allows for short pumping distances and use of heated water, unheated bay water, or a mixture of the two. Consequently, the site at the Charles P. Crane Power Plant was selected for the waste-heat aquaculture project.

Crane aquaculture facility with Charles P. Crane Power Plant in the background.

Raising Rockfish

In September, 1981, management approval was obtained to proceed with the design and construction of the aquaculture facility. Trident Engineering of Annapolis, Maryland, was enlisted to aid the engineering staff at BG&E in designing the facility. Construction began in July, 1982. The facility was designed as an intensive culture system (many animals in a small space, as opposed to a spread-out pond culture system) with a capacity for one million two-inch-long striped bass fingerlings.

Morone saxatilis, the striped bass, is known in the Chesapeake Bay region as the rockfish. It is the state fish of Maryland, highly prized by both commercial watermen and sportsfishermen. However, commercial landings of striped bass in Maryland dwindled from 5 million pounds in 1973 to less than half a million pounds in 1982. The exact causes of this decline have not been determined; contributing factors probably include overfishing and reduction of spawning success. Pollutants, disease (especially in early life stages), and contaminants in the eggs also may be contributing to the rockfish's decline. Whatever the problems are, they affect not only the Chesapeake but the striped bass population all along the eastern coast of the United States.

The Maryland Department of Natural Resources (DNR) has had a modest hatchery program for the production of striped bass fry and fingerlings to bolster the reproduction of the natural population since the late 1970s. It was after discussions with DNR that BG&E won approval to produce striped bass for release to the Chesapeake

Bay. The BG&E aquaculture facility would take advantage of the waste heat from the power plant to encourage more rapid fish growth, so that larger fingerlings could be released. Larger fingerlings have improved chances of survival.

On the first of March, 1983, we were ready for fish. A typical operation cycle begins in the spring (April to May) when we purchase one-day-old striped bass sac fry in lots of 200,000. Each lot is transported to the facility in a plastic bag filled with oxygen-saturated water. The bag is put in a styrofoam cooler to maintain temperature during transportation. Upon arrival, the fish are temperature-acclimated, just as is done with new fish in a home aquarium: the bag is floated in the tank (in this case, an upflow box; see Lewis, Heidinger, and Tetzlaff, 1981, for a description of this device). As soon as possible, we release the fish into the circulating water of the upflow box. All water is pumped directly from the warm-water discharge canal, without filtering or alteration, to a head tank. At two gallons a minute, warm water from the head tank enters the bottom of the system and moves upward. This gentle upflow helps to keep the small fish in suspension. The water exits at the top of the box through a 0.5 millimeter mesh screen.

Sac fry depend exclusively on yolk for nourishment; striped bass sac fry do so for the first five days after hatching. Their mouths become functional at this time and the larvae are ready to begin feeding. Striped bass require live food for the next few days, and since it takes 48 hours to hatch the food (brine shrimp), this operation must begin on the third day of the fishes' lives. For 1.2 million fry we need 180,000,000 brine shrimp a day for 10 days.

On day 14, the surviving small fish (less than a quarter of an inch long) are removed from the upflow boxes and placed in 550-gallon fiberglass tanks, each 6 feet in diameter. There they are given powdered food to acclimate them to dry fish foods. Water enters the tanks from above, through a degassing column, and exits the tank through a slotted screen. The degassing column is a pipe packed with small plastic rings that work to equilibrate gasses dissolved in the water with atmospheric levels. This prevents water containing either too little oxygen or too much nitrogen from entering the tanks.

Since it is springtime during this part of the operation cycle, bay water temperatures are gradually rising. To maintain water temperatures close to optimum for fish growth, and to reduce temperature fluctuation, we begin mixing bay water with the warmed discharge water. As temperatures rise through the summer, we use less and less waste hot water, and more bay water; during the winter, we use only waste hot water.

As the fish become accustomed to dry food, the size of the particles is gradually increased. The fish grow at different rates, so after about three weeks the smaller fish are separated from the larger to prevent cannibalism. The groups are transferred to 10,000-gallon tanks, where they remain for the next six weeks, or until they reach lengths of two inches. Water flow through these larger tanks is similar to that in the smaller units except each 10,000-gallon tank has five degasser tubes and can receive up to 500 gallons per minute, equivalent to three turnovers of water volume per hour.

Tank wing of hatchery with degassing columns hanging from the horizontal pipes. Each tank is 20 feet in diameter and has a 12,000-gallon capacity.

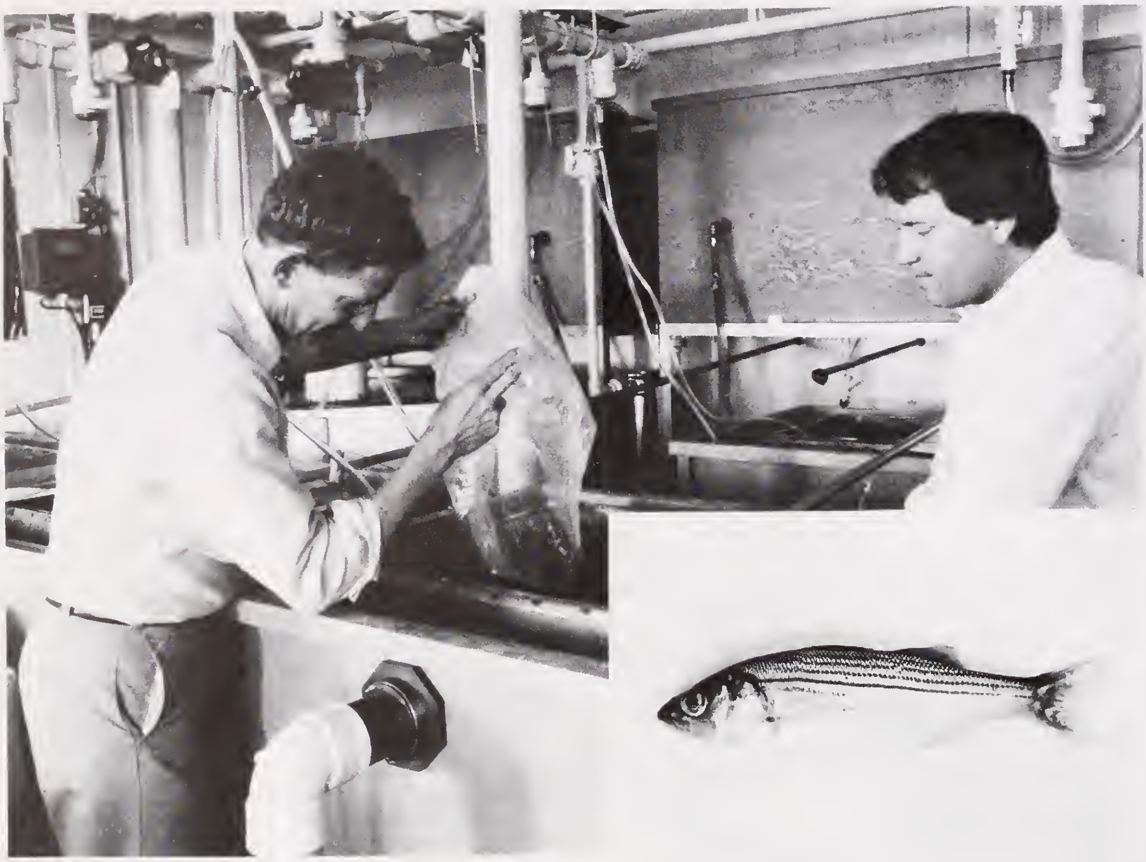
Our objective is to be able to hold up to 200,000 two-inch fish in each 10,000-gallon tank. At this size, metabolic demands will require thinning to approximately 30,000 fish per tank; those removed will be tagged and released into the Chesapeake Bay. This portion of the program is a cooperative endeavor with the Maryland Department of Natural Resources. The remaining 30,000 fish in each tank can be reared to four inches in length within the next month, at the end of which 15,000 will be released. The remaining 15,000 can then be grown to lengths of 6 to 8 inches before release to the Chesapeake Bay.

By fall, most of the fish were released; we are holding a small number of individuals over the winter to develop brood stocks. These stocks also will be used for studies on the effects of various diets on the development of gametes: very little is known about the nutritional requirements of striped bass for effective production of eggs and sperm. Moreover, by maintaining brood stocks in the warmed thermal discharge we should be able to ripen fish earlier in the spring and spread the spawning season over several months.

In Practice

In the first year of any operation, one should expect Murphy's Law to operate, just to be optimistic. Our problems began with the spawning season which, in 1983, was extremely short—about two weeks instead of the normal four weeks—the result of a prolonged, cold spring followed by a rapid temperature rise. Disease and start-up problems caused high mortalities. We sent samples of sick fish to researchers at the University of Maryland in the hope that they will isolate the major causative agents before the next breeding cycle. Probably the most peculiar start-up problem was that fry were eating air bubbles instead of the fish food.

In addition to the fish raised, BG&E received more than 20,000 1-½-inch-long striped bass from



200,000 day-old sac fry are placed in upflow tanks. Inset, hatchery-raised striped bass at 4 months, approximately 4 inches long.

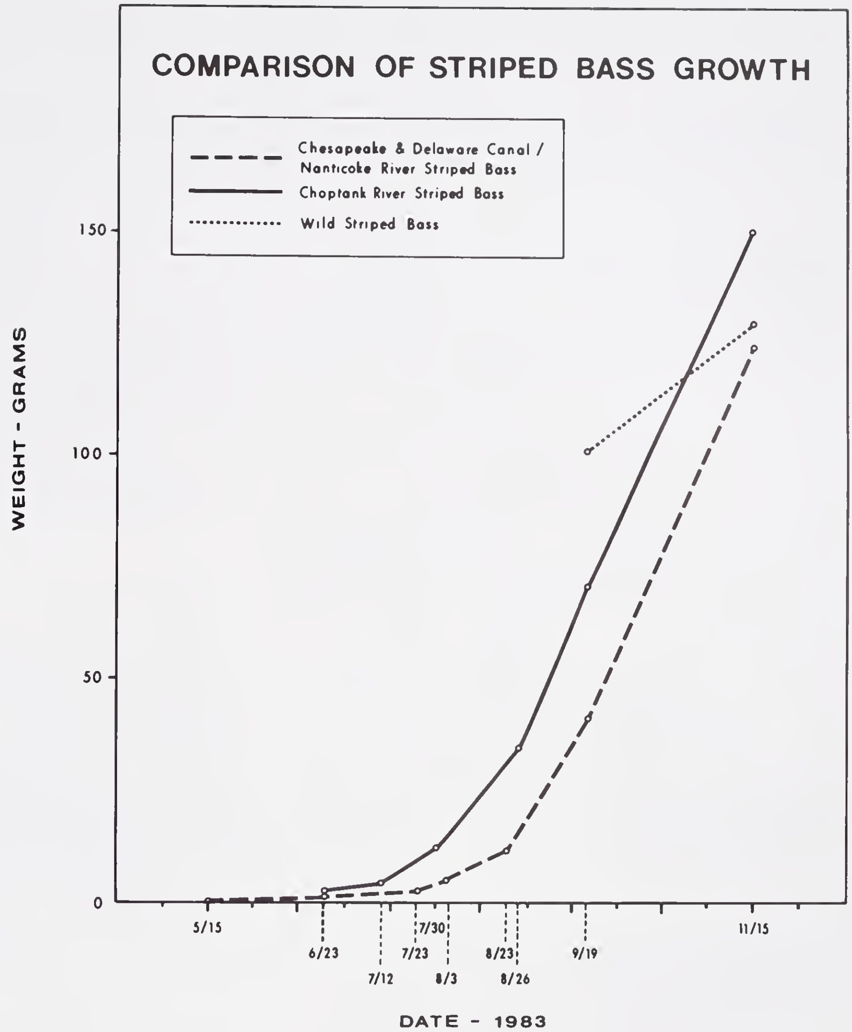
another hatchery. These pond-reared fish responded very well to the conditions at our facility. After nine weeks, they had grown to 4 inches or longer and gained an average of 34 grams each. This growth was sustained, even though the fish were infected with *Flexibacter columnaris*, a bacteria pathogenic to fish. *F. columnaris* causes hemorrhaging and death.

Luckily, we were able to treat and eliminate this disease. Some 18,000 of these fish were released to the Choptank River on the Eastern Shore of Maryland in August.

Before release the fish are branded in order to make them distinguishable from wild individuals. This marking will allow the Maryland Department of Natural Resources to more accurately estimate striped bass populations. We use cryogenic (freeze) branding, performed by holding the fish against a brass brand that has been cooled with liquid nitrogen. This procedure does not break the skin and causes negligible mortality; thus, for many purposes it is preferable to fin-clipping and other tagging procedures.

Production for 1983 totaled 21,565 striped bass, released to the Choptank and Nanticoke rivers and Chesapeake-and-Delaware Canal. Fry from parents collected in a particular river are returned as

White circles on side of fish indicate where they have been cyrogenically branded.



Weight comparison of wild striped bass (1982) and hatchery-raised fish (1983).

fingerlings to that river. One goal of the Maryland restoration plan is to maintain the particular riverine gene pools. The fish released were 4 to 8 inches in length and probably have a good chance of survival. More than 2,000 additional striped bass were distributed among several academic institutions for their research programs. About 600 fish were kept in the facility for studies on winter growth, and to develop our spawning stock.

Estimates (based on rather sparse evidence) from the Department of Natural Resources indicate that hatchery fish in the Choptank River may constitute 25 percent of that river's 1983 population. Six-month-old hatchery-raised fish are larger than 18-month-old wild fish (see graph); two stocks of 1983 hatchery-raised fish were 125 and 150 grams average weight per fish at the end of six-and-a-half months, while wild striped bass from the 1982 spawning averaged 130 grams each.

We have realized more than 2 percent of the goal of a million fish for release to the Chesapeake Bay. The waste-hot-water aquaculture design does work; it has supported the maturation of sac fry to fingerlings. Future efforts will aim at realizing our goal of a million two-inch striped bass a year grown in the heated effluent of a coal-fired power plant.

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Marine Science and Society in China

by Baruch Boxer

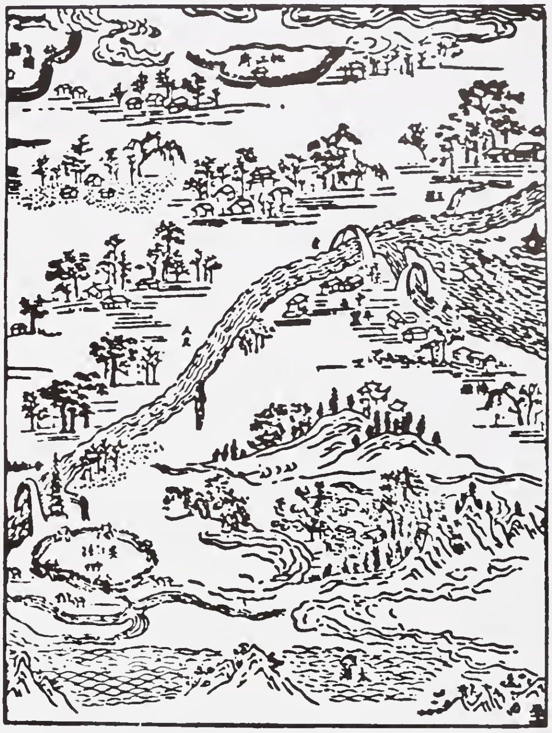
EDITOR'S NOTE: The following article by Professor Baruch Boxer of Rutgers University represents a slight departure from our usual format. The article was written for our last issue, *Oceanography in China*, but because of its potentially sensitive nature we delayed scheduling it until this issue. The article examines the social as well as the scientific significance of recent changes in Chinese marine science. In a way, it puts our previous issue into perspective for the discerning reader.

Much of what has been written about the goals, organization, and quality of marine science in China is based on outsiders' assessments. In recent years, Western visitors to China have commented on the strengths and weaknesses of Chinese work, on research opportunities for foreign scientists, and gratuitously, on potentially productive research directions for Chinese marine research.

Comparative review of Chinese efforts, however, ignores other important issues concerning the value of marine science to China. What can analysis of the background, scope, and institutional setting of Chinese marine research tell us about its importance in Chinese terms? This aspect is seldom addressed inside or outside of China. It raises questions about how to interpret the social, as well as the scientific, significance of recent changes in Chinese perspectives on marine research, especially as foreign contacts grow. Yet judgments on the ability of the Chinese marine science community to integrate indigenous and foreign research must be based on better understanding of social and cultural factors that influence the way priorities are set and work carried out.

Despite increased scientific exchange in recent years, there has been some understandable reluctance on the part of Chinese scientists to share more completely with foreigners their research assumptions and data. While this is changing, it is still difficult to interpret local marine research in relation to overall developments in China's science and science policy.

The problem, then, is how to devise a perspective on marine science research in China that provides insight into features of Chinese life and thought that have been influential in defining the scope of what generally have come to be known in China as "ocean studies." If approached in this way, understanding of how China's marine research program has come to be what it is can also broaden knowledge about relations between scientific initiative and other economic development objectives.



Panoramic map from Fu Cehong's Xing Shui Jin Jian (Golden Mirror of the Flowing Waters), circa 1725. The foreground lake is Tai Hu in Jiangsu and the wall-enclosed city to the left is Wujiang; the vista looks east. The Grand Canal crosses the panorama toward Hangzhou, past the village of Wangjing. Beside Wujiang the famous Chui Hong Qiao (Drooping Rainbow Bridge) is marked; two other bridges are shown.

What can be learned about the society that guides and supports ocean studies from the way research is conceived, questions asked, and methods applied? How does the evolution of Chinese marine research since the establishment of the People's Republic in 1949 reflect shifting views of the coastal ocean as a national resource? Do intellectual, social, and ideological determinants of these views have historical antecedents? Have geopolitical ambitions toward the distant ocean been important? Finally, are present notions of the relationship between marine science and policy suggestive of radical departures from earlier concepts of the importance of the sea to society?

These questions suggest that to properly evaluate the place of marine science in China we need to go beyond descriptive details of what kind of studies are done, how good they are, and their organizational context. A more difficult but challenging task is to discover what these studies can tell us about the Chinese sense of the ocean environment in relation to social well-being and national purpose.

Antecedents

At least two historical factors have strongly influenced Chinese thinking about marine research. First is the legacy of past attitudes about the coast and sea, and the extent to which these attitudes are reflected in modern research. A second dimension has to do with debates over the efficacy of scientific solutions to economic and social problems. There are striking parallels, for example, between the 1920s and 1930s and the present. In the earlier period, visionary Western-educated Chinese intellectuals were convinced that science, as practiced in the West, could offer guidance in managing these problems. Now, China's leaders confidently promote science and technology as a key prerequisite for modernization.

In both instances, there are idealistic expectations of quick benefits to society from the adoption of rational scientific approaches to national difficulties. But these hopes in the 1920s and 1930s were overly optimistic. Even today, they are based on sometimes questionable notions of the relevance of Western science to China. In part, this reflects fundamental differences between the origins of Western and Chinese approaches to scientific thinking. Traditionally, the dominance of metaphysical explanations for natural phenomena in China inhibited the development of theory-based and skeptical models of inquiry. Extensive data-gathering served to reinforce accepted views on natural phenomena that were sanctioned by the weight of historical precedent. It remains to be seen whether expectations of the inevitable benefits of science to society are warranted.

As for the past, there was little interest in the dynamics of coastal or oceanic processes despite China's long coastline and the growth of a sophisticated nautical technology that has flourished since the first century. Joseph Needham's monumental work on the history of Chinese science documents only a few references to scientific curiosity about the oceans. China's active maritime trade and exploration in the South China Sea and Indian Ocean were supported by impressive descriptive knowledge of hydrographic patterns, wind movements, and physical determinants of harbor suitability. But tidal action was the only theoretical area that aroused the interest of Chinese thinkers. Wang Chong, in his first-century work, *Lun Heng*, recognized lunar influence on tides. By the twelfth century, a number of Chinese scientists had produced studies on the lunar theory of tides and compiled still-accurate tidal tables. The Qiantang bore (*Qiantangchao*) at Hangzhou was the primary focus of study.

The major reason for this relative neglect of the oceans was the dominance of scientific work on the hydrography of rivers and waterways. China's early pre-eminence in the theory and technology of hydraulic engineering was put to use in elaborate water-conservancy schemes for irrigation, flood control, land reclamation, and transportation. There was a predominantly landward orientation as far as interest in water-related phenomena was concerned. Since human welfare was closely tied to maintenance of waterworks and waterways, it was not uncommon for observers to seek combined or analogous explanations for human and natural phenomena, or to propose interpretations that metaphorically linked natural and human systems.

A passage by Wang Chong as translated in Needham is illustrative:

> *Now the rivers in the earth are like the pulsating blood-vessels of a man. As the blood flows through them they throb or are still in accordance with their own times and measures. So it is with rivers. Their rise and fall, their going and coming are like human respiration, like breath coming in and out.*

Where does this leave the ocean? Apparently on the periphery of scientific speculation. Ancient approaches to management of the human environmental realm, by seeking to coordinate natural and social elements in keeping with cosmic and seasonal rhythms, failed to recognize marine meteorological influences or the linking role of sedimentation processes in the maintenance of hydrological balances between land and sea.

Another reason for the exclusion of coast and sea from early scientific purview was the cultural distinction made between the land as the domain of order and stability and the sea as the unpredictable and changing realm of demons and monsters. This mirrors opposing views in ancient times on theories of natural change. Writers as early as the third century B.C. noted that coastal peoples were more sensitive to changes in nature than inlanders because of their opportunity to observe the ocean and its changing configurations. The earliest Taoist magical-scientific traditions, in fact, arose in coastal feudal states around the Shandong Peninsula where Qingdao, China's leading oceanographic research center, is now located. In 219 B.C., Qin Shihuangdi, emperor of China's first unifying dynasty, the Qin, sent an expedition to discover islands inhabited by genii thought to possess formulae for immortality drugs. Qin Shihuangdi died in 210 B.C., at the mouth of the Huang He (Yellow River), while hunting sea monsters preventing access to these imaginary islands.

One might speculate that the rigid formality and hierarchical social structure of Confucian China required that definitions of what was scientifically acceptable must derive from observations sensitive mainly to the regularity of terrestrial events. The ocean, with its profound unpredictability, could hardly be expected to generate theories about relations between man and nature that would stand the rigors of time.

There is a final bit of evidence that underscores the anomaly of a nation endowed with a rich scientific tradition and an 18,000-kilometer coastline failing to develop a tradition of marine research. As early as the third century B.C., there were descriptive accounts of China's inland waterways. One of the earliest, the *Shui Jing*, described 137 rivers. The text of an updated revision published in the sixth century was about 40 times longer. In contrast, treatises on coastal geography and hydrography probably did not appear until the mid- to late-sixteenth century.

Some authorities on Chinese historical cartography speculate the coastal charts may have been produced as early as the thirteenth century. These speculations are based on recent archaeological evidence of greater coastal shipping activity from more ports during the late Song period (1127–1279 A.D.) than was previously assumed. Still, the earliest extant maps are from the late Ming. Preparation of these works was stimulated by the need for accurate information on coastal and nearshore conditions in the face of Japanese pirate raids. National defense concerns, not scientific curiosity, directed attention to coast and sea.

These trends and attitudes are reflected in the uncertain evolution of marine science in China during the last 50 years. Its development documents the trials Chinese scientists have faced in relating foreign science to their own needs. Part of the challenge of this adjustment also reflects China's traditional (especially from the mid-fourteenth through late-nineteenth centuries) inward-looking, exclusionary stance toward the rest of the world.

Pre-World War II

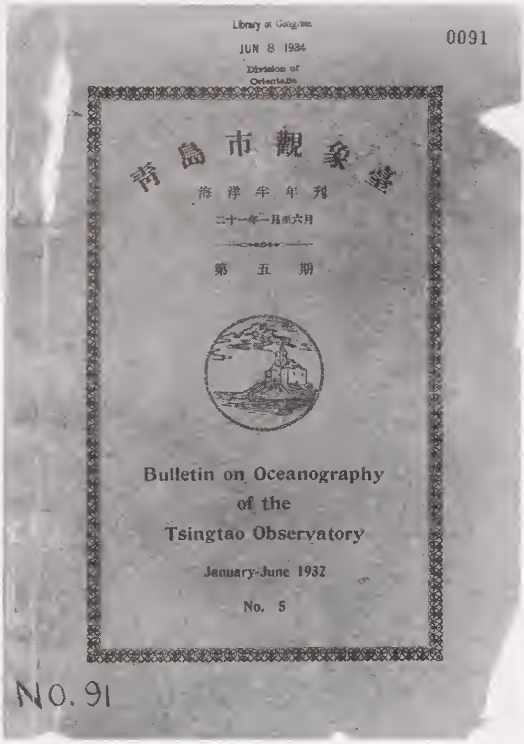
The case of marine biology, always the strongest area of marine research in China, is illustrative. As noted previously, in the early 1920s a small group of foreign-trained Chinese intellectuals actively sought to introduce Western scientific training and institutions into China. Their purpose was to illuminate China's path to modernity by propagating scientific approaches to solving problems of economic and social backwardness. Their faith in science, however, derived from abstract notions of the power of scientific thinking to change society. Significantly, the discipline of biology, that had perhaps the most realistic potential for dealing with resource and population issues, was downplayed. When China's premier national research organization, Academia Sinica, was formed in 1927, biology was not included among the nine research institutes established to pursue investigations in physical science, psychology, and other social sciences, and history and philosophy of science.

The mission of Academia Sinica was to train Chinese scientists and engineers to conduct surveys in support of resource utilization and industrial development and to foster technological skills through engineering applications. Ocean studies were ignored, and it was not until 1930 that a research institute with a marine focus was founded. This was the Marine Biological Laboratory at the University of Amoy (now Xiamen) on the southeastern coast in Fujian Province. Still, the legacy of past attitudes toward the marine environment persisted. Even though this laboratory boasted a marine designation, its investigations of flora and fauna included almost as much work on freshwater as on marine species.

This tendency to combine support for marine and freshwater biological research continued even after the establishment of the People's Republic. For most years from 1949 through 1981, about three-fourths of China's annual fisheries production was derived from marine, in contrast to freshwater, fisheries. The dominance of marine production, however, has not been proportionately reflected in research activities. Not until the late 1950s was formal recognition given the efforts to bring China's existing base of marine biological research up to "international levels." Chinese approaches to marine-fisheries conservation and management are still influenced by inland priorities.

For most administrative purposes, inland and marine fisheries fall under the common jurisdiction of a national water-products bureau. One result is that the only compilation to date of water-quality standards for fisheries was published in 1979 under the joint aegis of this bureau and the Ministry of Agriculture. There is no recognition here of the

Qiantang River bore near Hangzhou. (Courtesy of Cambridge University Press)



Oldest Chinese oceanographic journal catalogued in the Library of Congress. (Library of Congress)

problems faced in distinguishing between freshwater and marine species in choosing and justifying criteria for standard setting, monitoring procedures, or assessment of human health or ecological effects. Reported 1983 marine water-quality standards issued by the National Bureau of Oceanography (NBO) are classified by water body and vary according to the *use* of the water body, not by organism or ecosystem.

On the physical side, conditions were even less favorable for the development of marine-research interests before World War II. Except for some fragmentary data on harbor-water temperature, tides, and currents gathered by coastal meteorological observatories, pre-war physical oceanography was virtually nonexistent. The oldest Chinese oceanographic journal in the Library of Congress, for example, a copy of the "Bulletin of Oceanography of the Tsingtao Observatory," began biannual publication in 1929. The fifth issue, January–June 1932, contains information on Jiaozhou Wan's (Jiaozhou Bay, the location of Qingdao in Shandong Province) surface-water temperature in comparison to surface-water temperature outside the bay, tides, "records on testing," and "seawater temperature."

The only other pre-war work of any significance appears to be a series of studies of past climates and continental drift and global geosynclinal formations in relation to pretroleum origins prepared in the late 1930s and 1940s by T.Y.H. Ma. These were originally published during the war in geography journals, but after the defeat of the Nationalist regime by the Communists they appeared under new guise in a privately issued publication published in Taiwan.

1950–1959: Search for Direction

Foreign observers of the progress of Chinese ocean science since 1949 have tended to think in terms of three distinct development phases: an early period of growth from the 1950s through the onset of the Cultural Revolution in 1966, when attempts were made to define a place for marine-related work in the nation's overall scientific program; a disruptive and regressive phase that extended through the end of the Cultural Revolution into the mid-1970s; and the present period of growth and development in research and training that began in the late 1970s.

This oversimplifies what, in fact, has been a complex process of adjustment both to internal demands for relevancy to national objectives and to external influences that have governed the direction and style of Chinese marine research. Soviet scientific and technical advisers in China played an important role in the 1950s. Until the end of the decade, when Soviet-Chinese relations soured, Chinese marine science was influenced by Soviet approaches to ocean research. These considered marine investigations as integral components of comprehensive, large-scale hydrometeorological surveys focusing on climate dynamics and patterns, hydrology and water balance, estuarine studies, and physical regionalization.

Soviet advice, however, encouraged rather than stifled Chinese initiative. Ongoing Chinese work was substantiated in several important respects, and new research emphases were promoted and helped nurture China's newly awakened sense of the importance of the coastal ocean to economic development and national defense. In effect, the traditional emphasis on enhancing the productivity of agro-ecosystems through improved moisture conservation and more efficient nutrient cycling was extended through growing interest in problems of marine bioproductivity. This was a time when Chinese scientists put much effort into their already established work in seaweed cultivation and fish breeding.

Soviet oceanography was itself at a formative stage in the mid1950s. Soviet marine scientists, therefore, tended to be more sensitive and less condescending in dealing with Chinese counterparts than were scientists in research fields where Soviet achievements were clearly superior. Soviet writings on Chinese research needs (as presented in Chinese in Chinese journals) convey a desire to establish cooperative relations on an equal basis. The Chinese responded in a similar vein.

For instance, a lengthy commentary in 1958 by a leading Soviet scientist on the applicability of Soviet limnological and marine-research methodology in China was published in the key journal *Oceanologia et Limnologia Sinica*. It sought to equate Chinese and Russian interests in having hydrological research serve the cause of improving freshwater and marine fisheries, irrigation and surface-water distribution, inland-water

transportation, and pollution control. It also strongly endorsed the need to integrate basic and applied research so as to maximize national production potentials. This was to continue as a major research direction. By 1959, however, institutional developments and research activities had to respond to ideological determinants.

1959–1965: Establishing Roots

The years 1958 and 1959 were a crucial juncture for the Chinese marine-science community. Throughout the 1950s, Soviet-Chinese scientific cooperation laid the groundwork for increased professionalization of research and better definition of research goals. This cooperation had the backing of both the government and the Communist Party. With the severing of scientific ties to Russian oceanography, however, Chinese researchers found themselves on unsure ground.

The launching of the Great Leap Forward in 1958, an intense political campaign that demanded self-reliance in the application of technical and scientific know-how to increase production, removed any lingering doubts concerning official expectations. An important February, 1959, policy statement on "Make the Oceans Serve Socialist Construction" indicates that ocean scientists were struggling to define an appropriate role for themselves in response to national directives. Anticipatory excitement in facing the challenge of carrying out an ambitious research program, however, was tempered by uncertainty over the best strategies for meeting the challenge. A report on marine research by the National Scientific Technology Committee, published in 1959, noted that research goals were uncertain because of conflicting views of younger and older scientists on the relevance of advanced theories in efforts to "develop systematic studies based on practical situations," and on the need to follow the Party line, which directed that "task leads technology."

In taking stock of themselves at this transition point, marine scientists for the first time since 1949 confronted the past in relation to the present and future. The policy paper quotes an old saying—"look over the ocean and sigh"—which, in the context of the statement, bemoans the sorry state of marine research because of past disinterest in the oceans, while simultaneously acknowledging the giant task ahead if the goal of fully exploiting ocean resources is to be achieved.

Several themes that guided research emerged from this early stock-taking. They persist to the present, despite the broadening impacts of re-exposure to foreign science since the late 1970s. Most important was that research should facilitate maximum exploitation of living and nonliving marine resources while also serving to define limits for conservation. Enthusiasm for the exploitative potential of China's continental shelf underlies the observation that China has the largest "shallow sea area along coastlines" of any country, and a mainland coastline of 18,000 kilometers, together with the coastal perimeters of 3,400 islands.

There also is clear reaffirmation of the inseparability of research on saltwater and freshwater fish and shellfish, and on the need for oceanographic surveys to provide information in support of work in marine physics, chemistry, and geology, as well as marine biology. Nearshore surveys, still a major activity, were justified as necessary to increase production and to support national defense. An early notion was that knowledge of the distribution and movement of luminescent plankton could be applied in exposing the presence of enemy vessels off China's coast.

The earliest surveys, in the late 1950s and early 1960s, gathered data on ocean currents, tides, seawater density, oxygen levels of seawater, and coastal geomorphology. A key assumption was that surveys initially should be organized to cover as wide a geographical area as possible, and to gather extensive data. Subsequent operations were expected to use these data to design field and laboratory investigations focused on localized phenomena (for example, Kuroshiro current, deep-sea fisheries in particular areas) or to support theoretical work in various disciplines. The latter objective has been difficult to achieve.

A distinction has always been made between "investigations" and "research" in the parlance of Chinese marine science. This originated in the early 1960s and has been reflected since in the organization of institutions and funding priorities for marine research, in the job designations of personnel, and in the allocation of responsibility to various government agencies for various coastal management and security functions. "Investigations" (surveys) usually have been carried out jointly by national and province-level agencies concerned with production (including aquatic products, oil and gas, industrial chemicals) in cooperation with teams of scientists from research institutes of the Academy of Sciences, universities, or government bureaus. Lead agencies for "investigations," however, have tended to be production-oriented, and data-gathering generally has been unresponsive to basic research needs.

"Research," on the other hand, has focused on theoretical questions that have practical applications. Work in marine physics (currents; tides, tidal streams, and storms; waves; acoustics, and more recently, air-sea interaction), geology (geotectonics; sediment formation; coastal and seafloor geomorphology), and chemistry (hydrochemical characteristics; background radiation; trace-metal analysis; geochemical processes) is typical. As might be expected, field data has been put to best theoretical use in marine biology.

Difficulties faced by Chinese marine scientists in using field data more effectively in theoretical investigations, and their tendency to develop elaborate analytical models that have little to do with field observations, were noted by Russians in the 1950s and by Americans in 1978. Just prior to the breaking of scientific ties with the Soviet Union, one Chinese scientist observed that Russian criticism of Chinese research in marine biology noted that too

much emphasis was being given to classification, and not enough to attempts to understand the laws governing ecological variations, distribution, and quantity of organisms.

1966–1976: Cultural Revolution

Standards for evaluation of scientific work as a measure of social development and need were thrown into confusion with the advent of the Cultural Revolution in August, 1966. Until then, marine scientists had struggled with some success to combine theoretical and applied perspectives on ocean-resource use and still satisfy Party-inspired demands for relevance to dogma. With the social disruption that accompanied the Cultural Revolution, however, even the most dedicated scientist found it difficult to maintain a semblance of order in work or political thinking.

Anarchy reigned in many institutions, with politically favored, but not necessarily competent, personnel assuming influential administrative and research positions. Some of the best researchers, deemed hostile to the ever-changing ideological climate, were forcibly expelled from laboratories, thereby undermining long-established research programs. Senior scientists with foreign training were most notably affected. At times, the uncontrolled zeal of youthful revolutionaries, spurred on by competing Party factions, threatened to completely undo the marine science research system. Chinese researchers also were completely cut off from developments in Western marine science. They still are struggling to overcome the effects of 10 years of isolation from the technical and theoretical advancements made in the West during this period.

There were a few cases, however, where demands for making science more relevant to the needs of the masses had beneficial results. In the 1950s, research on marine plants and freshwater fishes began to follow the dictum that "theory is the result and product of practice and reality." This was given new impetus in the late 1960s. Many laboratory scientists concerned with genetics and cell development were forced to work more closely with field workers. This helped lay a foundation for work on primary productivity, chemical-nutrient cycling, and plankton availability in relation to yield prediction that is now quite advanced. In a sense, the chaos of the Cultural Revolution served in a limited way to integrate theoretical and applied studies and to bridge the gap between field and laboratory investigations. This was true, as well, in the marine-ecology and environmental-research areas. The extensive surveys of marine environmental conditions undertaken in China's coastal seas in the 1970s could not have been mounted but for the training in assessment and monitoring techniques offered in a few places (especially the Dalian Institute of Chemical Physics) in the late 1960s.

1976–Present: Ideology and Readjustment

With the current emphasis in China on material incentives, economic pragmatism, and greater local responsibility for production decisions, it is easy to forget that, in theory at least, Chinese social development still responds to shifting trends in Party ideology. In our haste to assume that recent liberalization moves herald a rapid "opening up" of the Chinese society and economy, we tend to overlook the continuing influence of ideological theory on scientific work. In marine science, as in other fields, research directions have emerged in response to both ideological directives and new science-policy goals.

Marine science, perhaps, has been more vulnerable in this regard than physical- and natural-science fields with more narrowly focused research agendas. Its diverse subject matter must be justified in terms acceptable to government agencies that often have only peripheral interest in, or sympathy for, marine concerns. This may be attributable, in part, to the traditional lack of interest in ocean matters, and is still true despite the fact that the National Bureau of Oceanography, the only national-level marine agency, retained its authority and autonomy in a major 1982 government reorganization of ministerial-level units. Also, continuing obsession with coastal security places administrative responsibility for coastal and nearshore activities with such agencies as the People's Liberation Army, the Ministry of Communication (ports and harbors), and the National Offshore Oil Companies, each of which is mainly interested in technical problems relating to its own mission.

It is significant that during 1979–80, when most scientific disciplines developed new research programs that tried to separate ideology and science in reaction to the excesses of the Cultural Revolution, spokesmen for marine science still outlined a direction that acknowledged ideological responsibilities, especially with regard to the relationships between society and environment.

A definitive 1980 statement in the inaugural issue of *Haiyang Kexue* (*Oceanography*) on marine biology and the Four Modernizations recalled some familiar production-related themes: surveys for energy and living resources; "basic" research on tides, currents, and geology; and marine biology/aquaculture. But attention also was called to the importance of pollution studies, especially in terms of responsibility to progeny. Ocean pollution is seen as a threat to human health. More important, however, it hinders the efforts of Chinese society, through socialist construction, to maximize utilization of the productive *potential* of the marine environment to serve the cause of development.

The term in Chinese for "theory" can refer as well to scientific theory or to ideology. Ecological theory as elaborated in the late 1970s and early 1980s illustrates correspondence between the two. It is assumed, in dialectical terms, that since everything in the universe is in motion, the objective of marine research is to understand how this motion can be 1) maintained, and 2) transformed so that the dynamic quality of marine ecosystems can be exploited for productive ends. The study of "marine ecosystem dynamics" thus requires investigation of what these

"dynamic" qualities are, and how their characteristic features can be enhanced. Other concepts include the notions of "self-cleaning," "guarding-protecting" (as distinguished from our idea of conservation), and "transformation." In combination, these concepts touch on, but differ considerably from, what we mean by assimilative capacity. The main difference is that, in the Chinese context, it is the responsibility of society to intervene and modify natural systems so that the "dynamic" change that guarantees continued social development will never cease. Marine research must delimit and clarify the dimensions of this process.

Prospects

As we increase our collaboration with Chinese marine scientists, we will undoubtedly become more confident about what we think we know to be important scientifically to China. We should be cautious, however, in assuming that what the Chinese deem suitable for collaborative work or overseas study represents the full scope of their scientific interests in marine research.

A major effort has been undertaken to gain the benefits of foreign science and technology to support modernization and development. However, marine science in China must also respond to the basic needs of the more than one billion inhabitants of China in ways that reflect their current social and economic realities, not abstract visions of a "modernized" future. This distinction emerges quite clearly from scientific materials published for internal circulation. Inevitable conflicts over these different views are bound to persist. This is not surprising, given the difficult obstacles with which Chinese ocean science has had to contend, a continuing search for scientific rationales that reflect changing ideologies and the legacy of the past.

Baruch Boxer is a professor in the Department of Human Ecology at Rutgers University, and coordinator of International Environmental Studies. His current research focuses on comparative aspects of marine science and policy. He visited China, as a lecturer and researcher, in 1980 and 1982.

Acknowledgments

I thank Leo A. Orleans and Chi Wang of the Library of Congress for illuminating discussions, and for help in locating research materials. Peter Li was helpful in clarifying aspects of Chinese life and thought. Research was supported in part by the National Science Foundation (SES 80-07573), and the New Jersey Agricultural Experiment Station.

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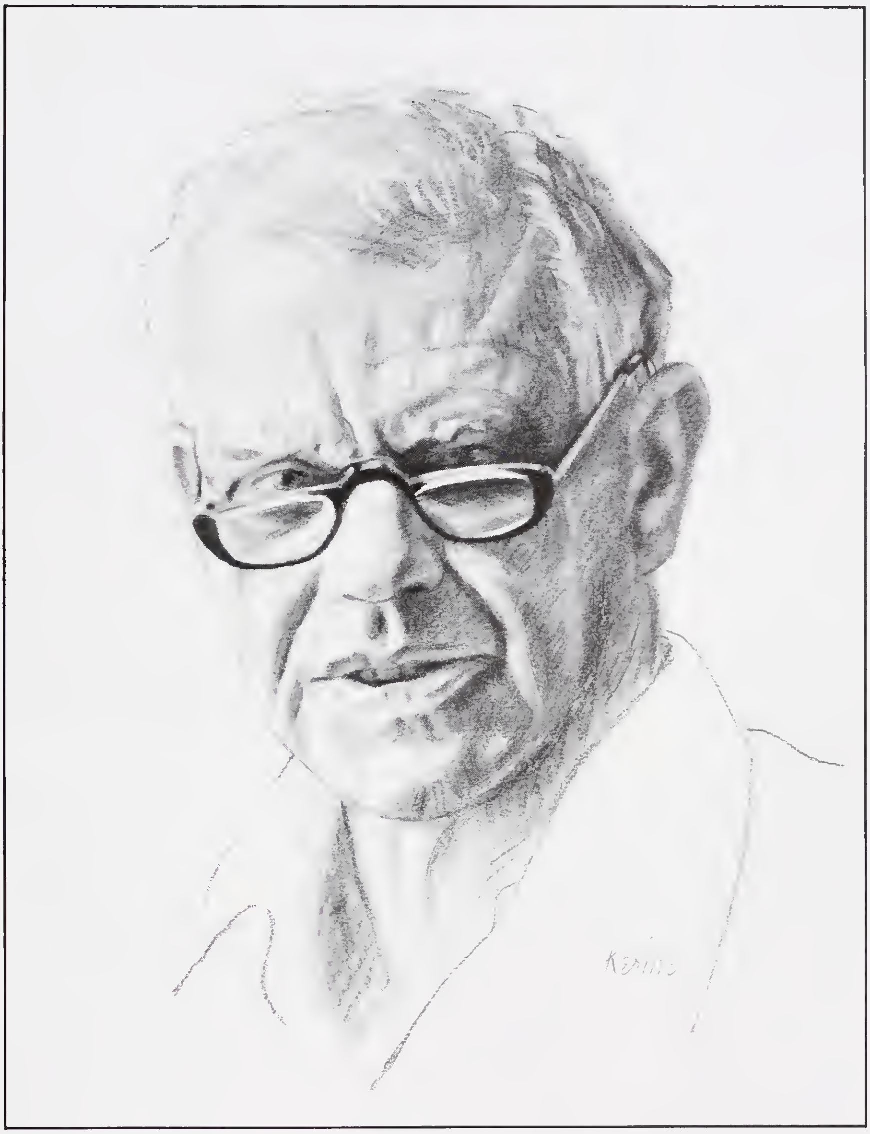
profile Henry Stommel



Portrait by Charles Kerins

'Apprentice' Oceanographer

by Paul R. Ryan

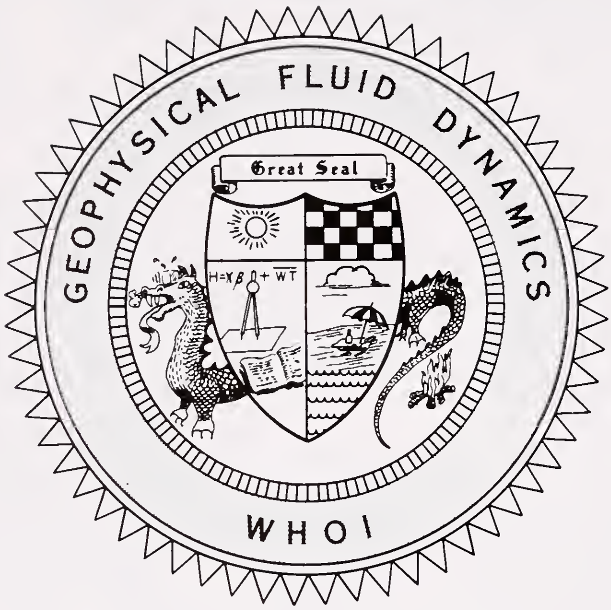
"Hank" Stommel has been known to sit in a lawnchair with a shotgun and a cigar, patiently waiting for Sippewissett woodchucks to invade his huge weed-infested garden in Falmouth, Massachusetts. This image reveals the physical oceanographer's style: a simple, common-sense solution to a critical problem.

Stommel, 63, short and stocky, given to wearing plaid wool outdoorsmen shirts accompanied by colorful

suspenders, is an acute observer. He also is a penetrating thinker, or theoretician as his colleagues would say. To visit him in his spartan office on the third floor of the Clark Laboratory on the Quissett campus of the Woods Hole Oceanographic Institution (WHOI), one would not suspect that this kindly looking, gray-haired marine scientist is the world's leading authority on the dynamics of the Gulf Stream—a study that has included observations by the likes of Benjamin Franklin, Matthew Fontaine Maury, and Columbus Iselin. Indeed, understanding the dynamics of the Gulf Stream is only one of Stommel's many accomplishments.

Stommel's more than 100 publications not only touch on almost all aspects of physical oceanography but, in the words of a colleague, "into cloud physics, limnology, and estuarine circulation. There are observational and theoretical papers on oceanic and limnological thermoclines, on time-series observations of thermal 'unrest,' on the formation and sinking of water cold enough to drop to the bottom, on oceanic Rossby waves, on monsoon effects in the Indian Ocean, on tidal mixing and density currents in estuaries, on the Kuroshio, on dynamical transients in the ocean—all containing some illuminating physical insight or significant observational data."

These publications have generated many distinguished awards. But what of the man? It is obvious that interviews are not among his favorite pastimes; in fact, it is his hope to discourage them whenever possible. One has to learn from other sources that in addition to being a gentleman farmer, he is also an amateur painter, printer, Oriental chef, marine antiquarian, music-box lover, opera singer, toymaker (built his own sit-in train set in the backyard that was powered by a lawnmower engine), sheep raiser, and an alarmingly casual experimenter with explosives (for many years, until his son had a small accident, he made his own Fourth of July display for the neighbors). But let us begin at the beginning.



Henry Stommel's design of the Great Seal of the Summer Study Program in Geophysical Fluid Dynamics at WHOI. The dragon, cooled from above and heated from below, emblemizes early program interest in convection.

Early Years

Henry Melson Stommel was born on the 27th of September, 1920, in Wilmington, Delaware, the only child of Marion Melson. He has two half-brothers and a half-sister living in Sweden.

His mother was a very successful fund raiser for large hospitals, and the family moved to Brooklyn, New York, early in Stommel's childhood. As he grew up in the midst of the Depression, attending public schools, one has only the image of the schoolboy often sitting in his small attic room, pouring over well-thumbed copies of *Popular Mechanics*. Beside him on a table—his chemicals and a copy of *The Boy Scientist* by Frederick A. Collin. If the attic room was a little cold in winter, it was because there was a hole punched through the roof for a telescope.

At the age of 18 in the year 1938, Stommel entered Yale University from which he earned his only degree in 1942—a B.S. (Phi Beta Kappa) in physics. He stayed on at Yale, first considering the possibility of divinity school, and then taking a job as instructor of mathematics and astronomy through the wartime years of 1942 to 1944. He was a conscientious objector to the war. Working at WHOI was considered an "acceptable" substitute for military service. His first job, however, was with Maurice Ewing, whose group was doing a Coast and Geodetic Survey chart of the Mississippi Delta. Stommel's initiation into oceanography was instrument monitoring at an isolated station in the far reaches of the Delta.

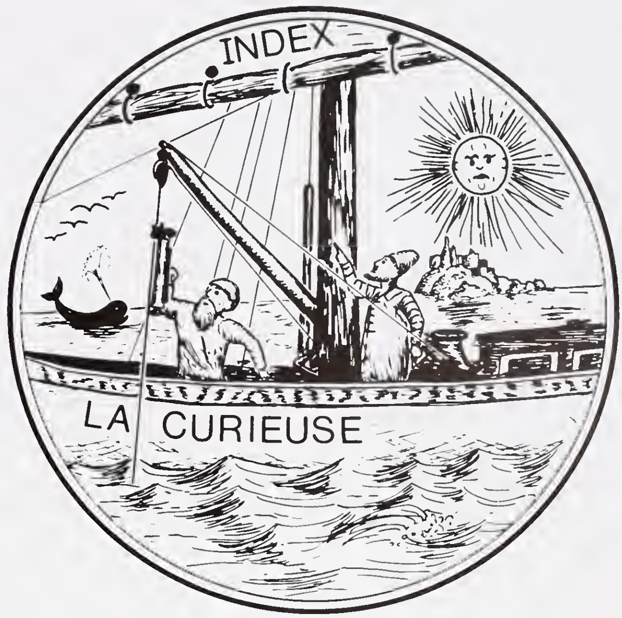
The next year—1945—he published his first book, *Science of the Seven Seas*, a popular work on oceanography. Stommel was subsequently denied admittance to the graduate school at Scripps Institution of Oceanography—then under the direction of H. A. Sverdrup. According to a

colleague, Stommel felt Sverdrup was annoyed at him for writing a nonprofessional book on oceanography.

Early in his stay in Woods Hole, Stommel took up residence in the old rectory of the Episcopal church on the east corner of Church Street and Woods Hole Road. The rectory at that time was the home of a group of WHOI bachelors who engaged in stimulating conversations about the oceans and, in the words of one attendee, "smashing parties." Stommel was soon showing an aptitude for fun, as well. A colleague remembers one event that Hank organized in which the rectory was transformed into "a gambling casino, complete with elegantly dressed madams and their charges. In each room, there was a different type of gambling—poker, roulette, and so on—plus music with a Gay Nineties theme. It was inventive and fun." Another colleague remembers an evening when Stommel played the organ and, "with a tremulous voice, sang Baby Hands, a very emotional funeral hymn that was sometimes sung at burial services for an infant."

During the early years, Stommel educated himself in oceanography. He was—and still is—a voracious reader, sometimes devouring as many as three books in one evening. He once told a colleague that at an early age an optometrist had given him an incorrect prescription that brought on headaches if he read for any length of time, so he had learned to read fast to avoid the headaches, eventually prescribing another set of lenses for himself.

In the early fall of 1947, he took a leave of absence without salary (at that time, $1,300 per annum) from WHOI and traveled to England where he met many notable oceanographers—among them Sheppard, Brunt, Francis, Deacon, Swallow, and Charnock. A trip to Scotland produced a collaboration with L. F. Richardson—a study of turbulent eddy diffusion. This was accomplished by measuring the separation with time of pairs of



Stommel drew this logo for INDEX, which undertook studies of monsoon currents in the northwestern Indian Ocean during the 1970s. La Curieuse was the charter vessel used by Stommel and collaborators for research out of the Seychelles.

parsnip pieces thrown from a pier into a lake.

In 1950, he married Elizabeth Huntington Brown, a Minnesotan transplanted to Woods Hole, after a courtship of several months. They soon had two sons, Elijah and Matthew, and a daughter, Abigail. "Chickie," as his wife has been called since childhood, recalls attending a WHOI Christmas party a few years after their marriage and overhearing two secretaries referring to her husband as "that entertaining man," a quality not readily apparent at home during those early child-rearing years. Still, if things were "intense" at times and Stommel had "to be pushed sometimes to be firm about something," there were always the toys that he made and the happiness that he almost always radiated. "He gave our children a priceless gift—he showed them that you could love your work and be happy doing it."

Elizabeth and Hank collaborated on a book entitled *Volcano Weather: The Story of 1816, The Year Without A Summer*, published in 1983 by Seven Seas Press. They are presently toying with an idea for a children's book. "Hank does the writing and I do the research" is the way Chickie puts it.

In oceanography, the 1950s were prolific years for Stommel, whose research "embraced an ever expanding set of ideas." A close colleague has written: "Noting that turbulent processes in the stably stratified upper ocean would cause a downward flux of heat, he [Stommel] assumed a deep upwelling of cold water to keep the temperature constant at a given level. The resultant circulation patterns of the abyssal waters had not been anticipated previously and were reported in short notes to *Nature* (1957) and *Deep-Sea Research* (1958)." In the mid-1950s, Stommel was one of the prime movers who set up the Geophysical Fluid Dynamics seminars between WHOI and the Massachusetts Institute of Technology (MIT)—seminars that are still producing important ideas today. He also began his synthesis of ideas and observations about the Gulf Stream about this time, completing a first draft of his book *The Gulf Stream* in 1955. A year later, he began studying

what has been termed "the perpetual salt fountain," a phenomenon in which the salinity distribution in the thermocline drives vertical motions.

The year 1960 was a critical one for Stommel. His children were growing up. His salary was $9,000 a year after 16 years in the same job. He was conscious of the fact that he did not have a Ph.D. and considered going back to graduate school at Scripps. What some have called a "palace revolution" and others "an experiment in communication" was under way at WHOI, an institution in the throes of growing pains. He was offered a position as Professor of Oceanography at Harvard and accepted.

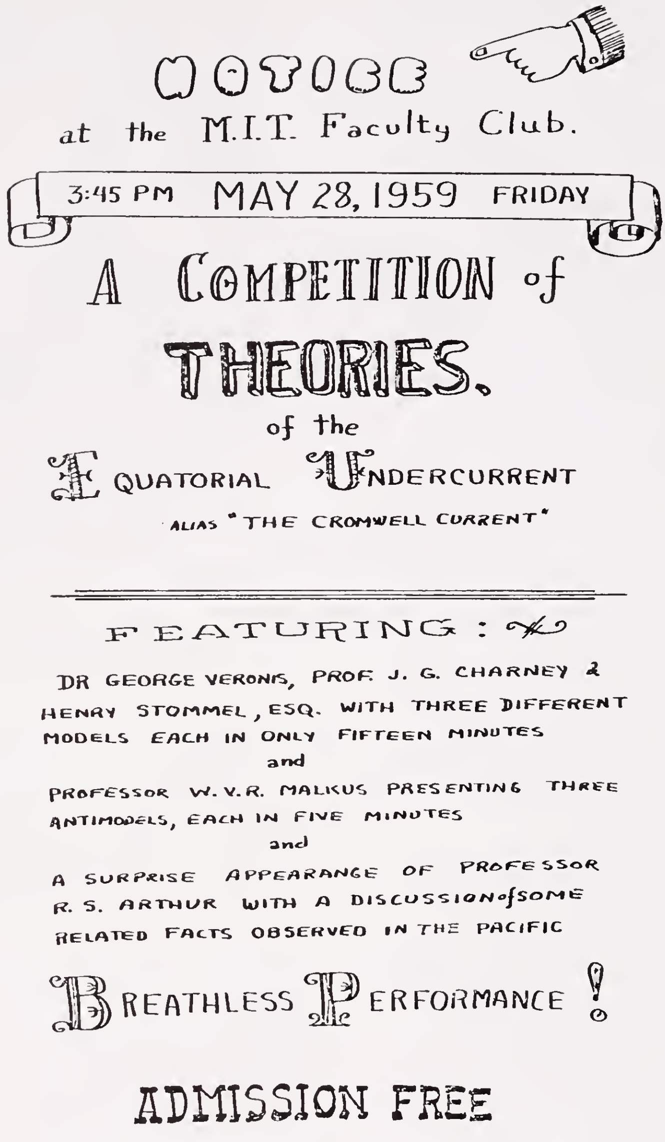
Stommel, however, never felt comfortable at Harvard. He felt there was too much "pose." A colleague commented that "he missed the daily discussions with observational oceanographers and the immediate access to oceanographic data that he had enjoyed at WHOI." In 1963, he left Harvard for a position in the graduate Meteorology Department at MIT, where his efforts involved less emphasis on teaching. He could wear bluejeans again to work and mingle with engineers and machines and not worry about the grease stains. During the 60s and 70s, Stommel commuted to Cambridge two or three times a week, spending the remainder of the work week at WHOI.

During the 60s, he became increasingly involved in big ocean science, taking an interest in the Indian Ocean and helping to establish international observation programs. Stommel played key roles in getting the Geochemical Ocean Sections Studies (GEOSECS) and the Mid-Ocean Dynamics Experiments (MODE) programs launched.

In 1961, he was awarded an honorary M.A. degree by Harvard University. In 1964, the University of Gothenberg, Sweden, awarded him an honorary Ph.D. Yale and the University of Chicago would follow step in 1970.

Of all the awards that Stommel has won, and they are legion, he probably enjoys the 1966 Albatross Award as well as any. The award—consisting of a stuffed albatross—is given by the American Miscellaneous Society for the year's most peculiar accomplishment. Stommel was cited for "abandoning oceanography's most cherished chairs"—a reference to his abrupt career changes in the early 60s. Stommel, himself, was at one time president of the Society of Subprofessional Oceanographers (lacking Ph.D.s), proposing an annual William Leighton Jordon, Esq., award that would go "to the oceanographer who makes the most misleading contribution to his field; and that ignorance and incompetence do not automatically qualify."

In 1979, Stommel moved back to WHOI as a full-time Senior Scientist. In 1981, a book entitled *Evolution of Physical Oceanography: Scientific Surveys in Honor of Henry Stommel* was published, edited by Bruce A. Warren and Carl Wunsch. In the preface, the editors, with slight rewording, quoted from



NOTICE

at the M.I.T. Faculty Club.

3:45 PM MAY 28, 1959 FRIDAY

A COMPETITION of THEORIES.

of the EQUATORIAL UNDERCURRENT

ALIAS "THE CROMWELL CURRENT"

FEATURING:

DR GEORGE VERONIS, PROF. J. G. CHARNEY & HENRY STOMMEL, ESQ. WITH THREE DIFFERENT MODELS EACH IN ONLY FIFTEEN MINUTES

and

PROFESSOR W. V. R. MALKUS PRESENTING THREE ANTIMODELS, EACH IN FIVE MINUTES

and

A SURPRISE APPEARANCE OF PROFESSOR R. S. ARTHUR WITH A DISCUSSION of SOME RELATED FACTS OBSERVED IN THE PACIFIC

BREATHLESS PERFORMANCE!

ADMISSION FREE

Stommel's *The Gulf Stream* (1958, 1965). The passage reflects his rigorous approach to his work:

> *I should like to make it clear, finally, that I am not belittling the survey type of oceanography, nor even purely theoretical speculation. I am pleading that more attention be given to a difficult middle ground: the testing of hypotheses. I have not explored this middle ground very thoroughly, and the few examples given in this book may not even be the important ones; but perhaps they are illustrative of the point of view in which attention is directed not toward a purely descriptive art, nor toward analytical refinements of idealized oceans, but toward an understanding of the physical processes which control the hydrodynamics of oceanic circulation. Too much of the theory of oceanography has depended upon purely hypothetical physical processes. Many of the hypotheses suggested have a peculiar dream-like quality, and it behooves us to submit them to especial scrutiny and to test them by observation.*

The editors commented that the convergence of theory and observation is presently "growing closer and more evident." And that the passage offers "an overall definition of the evolution of physical oceanography during the latter half of the 20th century."

The awards have been bestowed in sizeable numbers—among them the Alexander Agassiz Medal of the National Academy of Science in 1979 and the Bowie Medal of the American Geophysical Union in 1982. In accepting the Bowie Medal, Stommel commented:

> *Let me affirm that the freedom to work full time in science, on one's own, with congenial colleagues, unfettered by supervision, with a scientific problem in one's mind when he goes to bed and when he awakes next morning, and to be able to give undivided attention to unraveling some puzzle of nature is a privilege beyond compare.*
>
> *. . . despite a vast accumulated literature, our ignorance of how the ocean actually works is vaster still. I do not dare to guess how great the unknown is . . . after 40 years of trying, we are still largely in the preliminary stages of understanding, and in a very real sense we are all apprentice oceanographers.*

Folklore has it that there is no Nobel Prize in mathematics because Alfred Nobel's wife ran off with a mathematician. Nobel also ignored astronomers, geologists, and biologists. In 1982, Holger Craaford, a Swedish industrialist, established the Craaford Award (700,000 Swedish crowns—about $116,000) to cover the four forgotten disciplines. Stommel and Edward Lorenz of MIT shared the prize in 1983. The WHOI oceanographer was cited by the Royal Swedish Academy of Sciences for his "fundamental contributions in the field of geophysical hydrodynamics that in a unique way contributed to our understanding of the large-scale circulation of the atmosphere and the sea."

history

The Naples Zoological Station and Woods Hole

by Christiane Groeben

EDITOR'S NOTE: The following article is an edited transcript of a lecture and slide presentation given by Christiane Groeben at the Marine Biological Laboratory, Woods Hole, Massachusetts, on 14 November 1983. The title of Ms. Groeben's address was "The Stazione Zoologica and Woods Hole: Early Associations." As the reader will find, the article also paints a fine portrait of Anton Dohrn, the colorful founder of the Naples Station.

All American biologists are familiar with the Zoological Station in Naples, either through having enjoyed its unrivalled facilities or from accounts of it which have been published again and again in the journals, both scientific and popular, of the two worlds. It is, beyond question, the greatest establishment for research in the world.

Taken in 1889, this photograph shows Anton Dohrn in his office at his Zeiss microscope.

Do not worry if you are not that familiar with the Naples Station—the above statement was published in 1897 in *American Naturalist*, apparently by the editors of that magazine. They were reporting on a visit by Anton Dohrn, the founder and director of the *Stazione Zoologica* in Naples, Italy, to Woods Hole, Massachusetts. Their reference to the Naples Zoological Station as "the greatest establishment for research in the world" came at a time when when the Marine Biological Laboratory (MBL) was still struggling in its infancy.

There always have been close relations between Woods Hole and Naples. "Woods Hole," to non-Americans, often stands for one large scientific community; it is only when one visits Woods Hole that one learns to distinguish between the various institutions, such as MBL, the Woods Hole Oceanographic Institution (WHOI), or the Fisheries (National Marine Fisheries Service). More than 100 years ago, in 1882, Spencer F. Baird asked Anton Dohrn for advice and technical information concerning the establishment of a seaside laboratory for the U.S. Commission of Fisheries at Woods Hole.

When, a few years later, Charles O. Whitman started to plan the MBL, he leaned very strongly on his "Naples experience": he had worked there during 1881 and 1882, the first American scientist to do so. In his letters to Anton Dohrn, Whitman repeatedly expressed his wish for a close collaboration between the MBL and Naples. It was Whitman, in an article published in *Science* in 1883, who first called Naples the "mecca of biologists"—after only 10 years of activity at the *Stazione Zoologica*.

In the 1920s and 1930s, the MBL and Columbia University supported a table at Naples, and during the last few years several scientists from the staff of the *Stazione* have worked at Woods Hole, including Alberto Monroy, the first non-American member of the MBL Board of Trustees, whose links with the Naples Station stretch back many years.

During its long and troubled history, the administrative character of the Naples Zoological Station has changed: what was once the private property of a foreigner (to Italy) has become a government-supervised institution. But the station has not changed in essence or purpose—to be of service to science, to promote new developments in science, and to remain spiritually independent as an international research institute.

Anton Dohrn

Anton Dohrn was born on 29 December 1840, in Stettin (now Szczecin, a seaport of Poland), the fourth child of Carl August

The Naples Zoological Station: this contemporary print (circa 1875) resides in the Station's archives.

and Adelheid Dohrn. Anton's grandfather, Heinrich Dohrn, a merchant in wine and spices, made a fortune in the sugar-refining industry. This allowed Carl August, after having studied law and commerce, to devote himself to his various hobbies. These included travel, translations from the Spanish, and music (he collected folk songs and knew whole operas by heart, which he sang while accompanying himself on the piano). However, Carl August's greatest interest was entomology. He became a well-known entomologist and established contacts with scientists all over the world; he corresponded with Carl Ernst von Baer, Carl Theodor von Siebold, Alexander von Humboldt, the Harvard entomologist Hermann H. Hagen, and A. S. Packard. Carl August passed this interest on to his son, Anton, who, at the age of 18, already had published his first article in *Entomologische Zeitung*, a journal edited by his father. After receiving a humanistic education, Anton Dohrn studied zoology at Königsberg (now called Kaliningrad, on the Baltic Sea), Bonn, Jena (now in East Germany), and Berlin—without too much enthusiasm. Zoology, as it was taught at that time, did not satisfy his curiosity or his interest in philosophy, literature, and music, and above all, it provided little human contact. Anton even toyed with the idea of becoming a bookseller.

Anton Dohrn's attitude changed, however, when he went to Jena to study with Ernst Haeckel. Through Haeckel he learned about Charles Darwin and his theories. Even dry zoological studies suddenly became intriguing because they were necessary to prove Darwin's theories. From then on, Darwin's work became a primary source of motivation for Anton Dohrn, in his own scientific work and, later, in the foundation of the Naples Zoological Station. Through the establishment of the Station Dohrn hoped to facilitate marine research so that a final proof of Darwin's theory of evolution might be obtained.

Dohrn's friendship with Thomas Henry Huxley led to Dohrn's first and only visit with Darwin, in 1870. Darwin fully approved of the project of zoological stations and gave material support of books and money. And it was Darwin who, in 1874, headed the subscription for £1,000 from English naturalists for the Naples Zoological Station.

A curious mixture of imagination, contacts, and coincidences led to the building of the zoological station at Naples. In 1865, Dohrn took part in an excursion to Heligoland (an island in the North Sea off the coast of West Germany) led by Ernst Haeckel. This was Dohrn's first contact with marine biology, and it seems to have been there that Dohrn, together with Haeckel, first tackled the technical difficulties of carrying heavy buckets of seawater home so that they could study marine

organisms with microscopes—that is, the few organisms that survived.

In 1867 and 1868, Dohrn went to Millport in Scotland to study arthropods. There he met David Robertson, a self-taught zoologist and owner of a chinaware shop, who was to found the Millport Biological Station in 1885. The two friends invented a portable aquarium that could be mounted on a beach and that would provide live specimens with running seawater. This aquarium may be considered the first cell, out of which grew the complex organism of today's Zoological Station.

Dohrn took this aquarium with him to Messina, Sicily, where he spent the winter of 1868 and 1869. The Strait of Messina was at that time famous for the richness of its fauna and flora and, after the great physiologist Johannes Müller stayed there, it became the mecca of the German "Privat Dozenten" (assistant professors). Having established himself comfortably in a private room overlooking the port, Dohrn decided that other scientists would be spared many difficulties and inconveniences if, upon their arrival in Messina, they had access to his equipment and (perhaps more importantly) to his diaries, which relate his experiences there. This would give them more time for their research. Consequently, Dohrn rented some rooms and convinced the Swedish Consul to take care of the "Messina Station" during his absence. (It was at Messina, by the way, that a Russian friend introduced Dohrn to the Polish-Russian von Baranowski family; the elder daughter, Marie, then a girl of 13, became Dohrn's wife 6 years later.)

In January, 1870, while sitting with the coachman on the post-carriage that connected Jena with the nearest railway station, Anton Dohrn had one of his lightning-stroke ideas. Having just visited the aquaria at Hamburg and Berlin, he decided it would be useful to connect his marine station with an aquarium open to the public. The entrance

This poster, produced by Comingio Merculiano in 1902 to advertise the Naples Aquarium on trans-Atlantic steamers, shows a "table" of rented lab space on the right.

fees would provide valuable help for behavioral studies for the scientists, but most of all, they would help to pay a salary for a permanent assistant to the station. This turned Dohrn's thoughts to Naples, a town that could be expected to provide more local visitors and tourists than could Messina.

In 1870, only two years after the unification of Italy, Naples was still living its glorious past as the capital of the kingdom of The Two Sicilies. With 600,000 inhabitants—Rome at that time counted only about 35,000—Naples was an important commercial and tourist center; as a European city it figured right after Paris in the ambitions of foreign diplomats.

Back went Dohrn to Naples, where it took all his skill, and a good deal of stubbornness, to convince the city authorities to grant him the use of a plot of land near the sea to build, at his own expense, a zoological station—something strange and suspect to the Neapolitan authorites. For fear of the worst, the first draft of the contract between the City of Naples and Dohrn contained the following conditions: no women and no cooking would be allowed in the building and nobody was to sleep there overnight.

From the very beginning, Anton Dohrn wanted his station to be not only useful but beautiful, apropos of a city like Naples. He included a sketch of the future building in a letter to friends in Berlin. A few weeks before, he had optimistically explained to the same friends:

> *I am going to establish in Naples a large aquarium for the public . . . I am going to lead this thing, once it is set in motion it will take up very little time . . .*
>
> *I know that the land behind the Villa Reale down by the sea is very cheap and the building stone can be obtained nearby. The tuff for the grottoes can be bought in masses from Vesuvius, fresh seawater is constantly available on the doorstep, and the animals occur by the million in the sea; all can be done very cheaply. No dying animals. Hurrah, it's a marvelous idea!*
>
> *I have already calculated that for 120 visitors daily for 9 months of the year I can have profits, running and everything. And how many more will come! And in rainy weather! You must congratulate me, the idea is ready money, freedom, independence and a nice home for my dear friends in Naples.*

A similar sketch finally convinced

the Mayor of Naples to give Dohrn a plot of land in the Royal Park (today's Villa Comunale). The foundations were laid in April, 1872. Only a year and a half later, in September, 1873, the building was finished. Looking back in later years, Dohrn himself was amazed at how he had succeeded in accomplishing so much in such a short time—despite the handicaps of being a foreigner, not speaking Italian, and being unfamiliar with the Neapolitan mentality. Three-quarters of the building costs came out of his own pocket; the rest was loaned by friends.

Art and Science

Dohrn's close friend Adolf von Hildebrand, a German sculptor, helped Dohrn design the classical façade of the building, which recalls the Florentine Renaissance. But Dohrn also wanted to depict the association of art and science. In 1873, the German painter Hans von Marées and Adolf von Hildebrand completed, in six short months, a panorama of frescoes showing scenes from Neapolitan life for the large room facing the loggia and the sea to the south. For this, the frescoe room, Hildebrand also created greater-than-life-size busts of Carl Ernst von Baer and Charles Darwin.

This room was intended as a place in which to relax and listen to music, but it soon had to serve as library. The idea behind creating such a room in a research institute aptly illustrates the ideals that Dohrn wished to promote. The so-called "Pergola frescoe" at the east side of the room shows the group of friends—Dohrn, Nikolaus Kleinenberg, Charles Grant, Hans von Marées, and Hildebrand—as they used to meet in the evening during the summer of 1873 for a glass of wine in the nearby Palazzo Donn'Anna.

The finished building contained pumps, machines, store rooms, and seawater tanks in the basement; the public aquarium on the first floor; a large laboratory for about 20 scientists and the frescoe room with the library on the second floor; and 12 smaller labs and living quarters for the custodians and assistants on the third floor.

For the construction of the aquarium, Anton Dohrn relied on the help of a very competent person—William Alford Lloyd. Dohrn met Lloyd, an English engineer, in Hamburg in 1868. Their mutual love of

The Naples Zoological Station Library, photographed in 1890, when it was still housed in the frescoe room.

The "Pergola frescoe," on the east side of the library in the Stazione, showing Dohrn and friends having a glass of wine at the Palazzo Donn'Anna in Naples. From left to right: Dohrn; Nikolaus Kleinenberg (at that time first assistant to the Stazione); Scottish; poet Charles Grant (seated, wearing a black hat); Hans von Marées (half hidden), and Adolf von Hildebrand.

The excursioners to the island of Heligoland. Standing, left to right: Anton Dohrn, Richard Greeff (Professor of Zoology and Comparative Anatomy at Marburg, Germany), and Ernst Haeckel. Sitting, left to right: Dr. Salverda, and Pietro Marchi (Florence).

music soon made them great friends. Lloyd had built the Hamburg Aquarium and the Crystal Palace Aquarium in London, where he developed new techniques to ensure sufficient oxygen input to the tanks and natural light conditions for the organisms, while visitors remained in virtual darkness.

The Naples Aquarium, with 24 tanks or grottoes of different sizes, contained only specimens from the Mediterranean. The equipment (tubes, pumps, and the like) had to be ordered from England and mounted in Naples under Lloyd's direction.

After 100 years the aquarium, with its unchanged character of red brick and iron, has not lost its fascination; it still attracts about 1,500 visitors a week.

Scientists started to arrive at the Naples Station in September, 1873. The first to come were the anatomist Wilhelm Waldeyer-Hartz from Strassburg (today, Strasbourg, France), and Francis M. Balfour and Edwin Ray Lankester, from Cambridge and Oxford, England, respectively.

In 1878, the beach in front of the Station was paved over and the long road stretching from Mergellina to Piazza Vittoria was built, cutting the Station off from the sea. After only a few years of activity, the original building became much too small for the large number of guest-scientists, and the living quarters were changed into laboratories. During the years 1885 to 1888, a second, smaller building was added on the west side. An iron bridge connected the two buildings. This time, building costs were sustained by the Italian government.

This second building was destined to become the physiology department. In 1876, Dohrn had established a department for botany and in 1887 another for bacteriology, following suggestions by Robert Koch.

In 1900, Dohrn collected funds in Germany for a third building to be added to the eastern side of the first, connecting with it through a courtyard; a fourth floor was to be added to the whole building. By 1905, the *Stazione Zoologica* looked much the same as it does today, with the exception of the library that, thanks again to international contributions, was inserted between the first and second buildings in 1958.

Anton Dohrn, of course, realized from the very beginning that the income from the public aquarium would cover only a minor part of the operating costs—besides being a not very reliable factor. He had to find the means to secure a sound income while at the same time keeping the institute completely independent of national or foreign influence. Dohrn often quoted the maxim "*do ut des*" (I give so that you give) which guided his efforts to obtain international participation and to guarantee freedom for research.

Dohrn mainly counted on four different sources of income: entrance fees from the aquarium; sales of preserved marine specimens and publications, and (for a short period only) of microscopical preparations; table fees; and an annual subvention from the German Empire of at first 30,000, and from 1888 on, 40,000 marks. The Station also received several extraordinary contributions from Italy and Germany.

The Table System

The table system still functions today, although in a somewhat reduced fashion because of worldwide financial restrictions and changes in the nature of science—individual scientists have given way to team work and joint programs. This system was another of Anton Dohrn's ingenious ideas. Based on the system of reserving or renting hospital beds against endowments or contributions, Dohrn decided to rent working places, or tables, at the Zoological Station; they are rented to governments, institutions, universities, or scientific bodies. For an annual fee of $500 (today $4,500) the contract partner had

the right to nominate one scientist per table per year; a table included the use of laboratory space, instruments, chemicals, the library and fresh animal supply, and also the assistance of well-trained personnel.

In 1876, only two years after the opening of the Station, 17 tables had been rented by 12 different countries. The German states, Russia, the Netherlands, Austria, Cambridge University, and the British Association all held tables. The Station's staff counted 14 members, including assistants, servants, technicians, and fishermen. Forty-six guest scientists worked at the Station during its first two years.

From 1873 to 1915 more than 2,400 guests worked at the Station. The number of guests grew, parallel to the growing number of rented tables, though ups and downs (mostly due to political events) were unavoidable.

Official relations between the United States and the Naples Zoological Station started in 1883—relatively late. They became somewhat stable about 10 years later and lasted until 1972, when the National Science Foundation decided not to renew its table contracts. All of Anton Dohrn's diplomatic skills and powers of persuasion were required to constantly increase the number of tables rented and to maintain existing contracts. He felt that only the table system could guarantee the independent, international character of the Zoological Station. Until the end of his life, Dohrn worked to improve this system.

Anton Dohrn was a fascinating man—though you might not think so looking at photographs of him. He was one of those rare personalities gifted with a special charm that immediately strikes a chord in others. In conversation or correspondence, Dohrn could easily transmit his thoughts and feelings, in what for him were the most important languages: German, English, French, and, later, Italian. Dohrn always hated "pose"; as he once said to E. B. Wilson*, he felt just as at ease with Neapolitan fishermen as he did with emperors and kings. He was never impressed by rank or position, only by personality.

The Johannes Müller, *the first steam vessel of the Naple's station, photographed circa 1883.*

Dohrn devoted these talents to the Zoological Station, doing an enormous amount of traveling to secure new table contracts, keep up old relations, or start fund-collecting campaigns. He was conscious of the importance of public relations. The institute was soon mentioned in English and German guidebooks, and to visit the *Stazione Zoologica* became a "must" for important people from all over Europe and the United States. All were cordially received, in the hope that once back home they would further the interests of the Naples Station.

What made the Station so special for scientists, regardless of field of interest or country of origin? In contrast to university and seaside laboratories, like those of T. H. Huxley, Ernst Haeckel, F. M. Balfour, Rudolf Leuckart, or Lacaze-Duthiers, the Naples Station was meant for independent work without any teaching commitments. It was open year round, and equipment and staff were at the complete disposal of the visiting scientists. The technical quality of the instruments was constantly improved not only by staff members, but also by the visiting scientists themselves, and

Dressed in the Scaphander apparatus, the diver is slowly let down into the water, connected to the host boat by two cords and an oxygen tube. Shown is Harry L. Russell, who in 1891 worked at the Naples Station on bacterial fauna, work he extended two years later to the Woods Hole *area.*

* American Zoologist, 1856–1939; taught at Bryn Mawr and Columbia, pioneering work in genetics, especially the function of the cell in heredity and the role of the chromosomes.

suggestions were readily accepted.

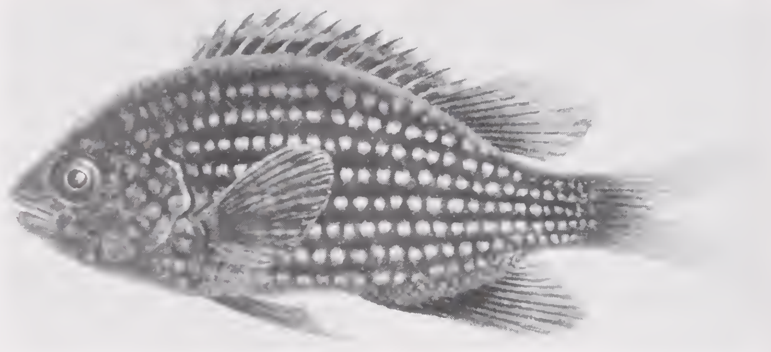
Dohrn had a friendship with Ernst Abbe, professor of mathematics and physics at Jena, dating back to his own time at Jena as a student. In 1876, Abbe entered the Zeiss factory where he helped build the worldwide reputation of Zeiss microscopes. Through Abbe, the Naples Station received sets of Zeiss instruments at a high discount, and in exchange, Abbe received valuable advice and suggestions for microscope improvement from the scientists working there—not to mention worldwide publicity.

Paul Mayer, one of the assistants, contributed substantially to the development of cutting and staining methods and microtechniques in general. In collaboration with the Jung Factory in Heidelberg, Germany, he developed the so-called "Naples clamp" and helped improve several microtomes.

Salvatore Lobianco

A third field where the Naples Station provided important innovation was in the preservation of marine animals and organisms. This was the merit of Salvatore Lobianco, who entered the Naples Station at the age of 14. He quickly learned to identify the fauna of the Gulf of Naples and acquired the expertise necessary to ensure their preservation. He developed these methods to such a degree that the Zoological Station became famous for the beauty and perfection of the collections of marine animals it sold to museums, institutes, and schools all over Europe; since these methods were kept secret for some time, this also meant a considerable income to the Station's budget. In recognition of his work, the University of Naples awarded Lobianco an honorary doctorate, and in 1883, at the International Fisheries exhibition in London, the Naples Zoological Station was awarded a gold medal for its collection of preserved animals.

Another area where Anton Dohrn continuously strove for perfect efficiency was in the fisheries department. In order to meet the requests of researchers for fresh material daily, and before he had his own trained personnel, Dohrn got the local fishermen to accept the somewhat strange idea that they could sell everything, not just edible fish, to the "fish doctors" at the "aquarium" (as the research station is known locally). This led to the development of the preservation department, in order to store what was not immediately used.



A plate from the monograph series, Fauna and Flora of the Gulf of Naples, famed for the precision of its plates.

The Station's fishermen mostly came from old fishing families from Mergellina, still a small village on the outskirts of Naples at the time. They soon acquired a remarkable knowledge of the best periods and places to find particular organisms. This knowledge has been passed on through three or four generations, and the daily supply of fresh material to guests and the aquarium tanks is still one of our most efficient services.

In 1876, the Berlin Academy of Sciences granted funds for a five-ton steam-launch; it was built in England and delivered to the station in May, 1877. The *Johannes Müller*, from the very beginning, was meant for work and pleasure; that is, Dohrn wanted it for fishing and dredging excursions and also to take visiting scientists and important guests on pleasure trips. Guests arriving in Naples soon counted on being taken out on the *Johannes Müller*. Memories of excursions to Ischia, Capri, Gaeta, and Sorrento are countless in letters and reports about Naples and the Zoological Station. In 1883, another, smaller steamer was acquired: the *Frank Balfour*, named after the great English embryologist and friend of Anton Dohrn, who had unexpectedly died the year before.

After some personal diving experiments in 1878 in the Bay of Kiel with his friend Werner von Siemens, Dohrn asked the Italian Navy for a loan of a Scaphander diving apparatus, which was subsequently used for botanical and ecological studies.

Another essential for good research, according to Dohrn, was a first-class library right next to the laboratories. Though Darwin thought this too difficult to realize, Dohrn, through his usual inventiveness, created a library that is still almost unrivalled for marine biology: he contributed his own rich library and asked editors and scientists to donate their publications.

In 1879, the Zoological Station began publishing *Zoologische Jahresbericht*. It soon surpassed similar English and German reference journals because of its efficiency, timeliness, and editorial accuracy. Dohrn decided that all publications sent to the station for review had to be placed in the library, the explanation for today's extensive reprint collection.

Two other publications were started at the same time: *Mittheilungen aus der Zoologischen Station Neapel* (later *Pubblicazioni*), meant for

assistants and guests, and the series of monographs called *Fauna and Flora of the Gulf of Naples*, the last volume of which was published in 1982. Two very skilled artists, Comingio Merculiano and Vincenzo Serino, were on the station's staff from 1885 to 1945. The series was first sold on subscription and was much appreciated, by non-scientists and scientists alike, for the beauty and detail of its plates.

All these services furnished the base for rendering the station—as Whitman said in 1883—"a sort of international depot for the reception of discoveries and improvements made elsewhere. The heterogeneous material thus obtained is sifted, systematized, tested, further elaborated and refined and redistributed."

Scientists expected to find new techniques and efficient working facilities at Naples, when they left they always took much more than just the results of their own work. Interdisciplinary discussions, new experiences and contacts, freedom from teaching—even from family ties—and freedom from the necessity of maintaining "pose" (important particularly for German professors) allowed a special creativity. I shall not tire you with long lists of important discoveries or contributions to science made at Naples; simply, Naples has contributed more than any other center to the transition from descriptive to experimental embryology and developmental physiology. This is mainly attributable to Hans Driesch and Curt Herbst, who brought the methods and theories of Wilhelm Roux and his "Entwicklungsmechanik" to Naples. It was at Naples that T. H. Morgan was introduced to experimental embryology, so important to his scientific development.

Letter from Watson

As another and more recent example of the role of Naples as a catalyzer, I include a letter from James Watson to Alberto Monroy written in 1980 on the occasion of the centenary of the birth of Reinhard Dohrn.

> ***Dear Alberto,***
>
> *Like many others, I went to Naples and its Zoological Station knowing that it had a treasured tradition and hoping that a little would rub off on me. Happily, this happened. There I met Maurice Wilkins and first realized that DNA might be soluble. So my life was changed, thanks to the use of the Station as a meeting place for the young. In particular, I remember the warm hospitality of the Dohrns who always made me feel wanted, even though, as a non-embryologist, I was a duck out of water.*
>
> ***Yours sincerely,***
>
> ***J. D. Watson****
> ***Director [Cold Spring Harbor Laboratory, New York]***

The decisive conversation between Wilkins and Watson took place at the beautiful remains of the Greek temples at Paestum.

Factors other than the good working conditions must have contributed to building this "creative atmosphere." The Neapolitan way of life, the beauty of the surroundings, and the fulfillment of old dreams played their parts, as did the feeling of belonging to a kind of family at this "permanent congress of zoologists," as Theodor Boveri called it in his commemoration of Anton Dohrn. But most of all, there must have been a feeling that the Naples Station was something more than just another lab; it was the expression of European culture and erudition at its best: art, music, world literature, and joy of life were all part of Anton Dohrn, and he was able to convey this to those around him.

One of the most touching results of this culture—music in this case—is the friendship between Anton Dohrn and Edmund Beecher Wilson. Dohrn himself never played an instrument, but there has always been a strong musical strain in the Dohrn family (remember his father's talents). Georg Dohrn, Anton's nephew, and Wilhelm Furtwängler, Anton's great-nephew, were both well-known opera conductors, and Anton Dohrn's second name was Felix, after his godfather Felix Mendelssohn-Bartholdy.

Wilson describes the beginnings of his friendship with Anton Dohrn in a letter to Reinhard Dohrn in 1933:

> ***Dear Reinhard,***
>
> *I have not meant to let so much time pass without writing you again, but I have been much preoccupied of late because of Nannie's illness, which has laid her up in the hospital for some time. We have every reason to believe that she will slowly pull out of it, but it is a very tedious and trying thing. I know she would send you her greetings were she here as I write.*
>
> *I was very happy to learn, a few days ago, that Columbia will join in the movement to secure a University Table at Naples. No doubt McGregor and perhaps Calkins have written to you about this, not to mention Conklin and others who have the matter more immediately in hand. I think there is little doubt, from what I learn, that the movement will go through, and certainly no one will be happier than I to see another table re-established at Naples. I hope indeed that this will be followed in due time by other subscriptions.*
>
> *I have been thinking much of Naples lately, owing to the fact that I have for some time been writing my reminiscences, not to publish—Heaven forbid—but especially for my daughter and my nieces in California. I have just got to the point of my first year in Naples, 1882–1883 I think, and have been trying to give some notion of the tremendous first impression made upon me by Naples and all that that word stands for in my memory. Prominent among these are my memories of your*

* Harvard biologist, shared the 1962 Nobel Prize in Medicine and Physiology with F. H. C. Crick and M. H. F. Wilkins, for work on the molecular structure of DNA.

father and mother and of your home in Ischia. I did not learn to know your father so well that first year and our close friendship did not begin until years later. It may amuse you if I recall what it was that brought us into such close touch. It was not science but music, and the ice was first broken one day as we sailed past the island of Procida. Your father hummed, to the accompaniment of the name Procida, the opening phrases of Schumann's String Quartet in A Minor, to which I immediately added a continuation of that remarkable beginning. "What," said your father, "Do you know Schumann's chamber music?" I did not reply, as I should have as a good American, "You bet your life I do," or even "I should smile" (if you know that bit of American slang), but at that moment began a friendship that never weakened through all the years that followed. My daughter loves that story, having often played that particular quartet herself.

I do hope that things are going well at the Station, and that some day you will come to see us all. Do give our warmest greetings to your family and believe me,

Affectionately yours,

Edmund B. Wilson

E. B. Wilson and his daughter Nancy (a well-known cellist) at Woods Hole in 1928.

Music remained the base of their friendship; their letters are full of reminiscences of concerts, especially with Joseph Joachim, the famous violinist, and the Mendelssohn family.

On the other hand, Wilson retained an active interest in the Station's affairs. He was on the advisory board for the Smithsonian Table and contributed much to the birth of the American University Table, sustained by Columbia and other American universities and societies.

In 1907, Dohrn asked Wilson, together with Theodor Boveri and Wladimir Schewiakoff, to form a scientific advisory board to assist Reinhard Dohrn as his successor. This never came about, but Wilson heartily agreed and readily extended his friendship to Reinhard after his father's death.

In 1906, thanks to the generosity of Alexander Henry Davis from Syracuse, New York, a major in the U.S. Army, a small summer house was built at the entrance to the port of Ischia. The "Villa Aquarium" holds dear memories for many of the Naples Station's guests. Today it houses our department of ecology and is used for meetings and the biannual Summer School of History of the Biological Sciences.

Anton and Marie Dohrn had four sons. The third, Reinhard, born in 1880, became Anton Dohrn's successor. He studied zoology at Marburg, Germany, and entered the Naples Station as an assistant in 1906. When his father died on 26 September 1909, Reinhard was able to continue the old traditions without any break, helped and guided by old friends and the Station's other assistants. These traditions—international participation and independent research, the creative atmosphere, and the permanent Congress of Zoologists—continued de facto, when as a consequence of World War I the institute became an *Ente morale*: an Italian, semiprivate institution. Reinhard Dohrn succeeded in keeping the Zoological Station free from political influence and out of national conflicts, so that after World War II, thanks to international contributions, the Station could resume its activity practically unchanged.

In 1954, Reinhard's son Peter Dohrn took over the directorship. After many years of searching for a new and solid constitution that would, above all, guarantee a sound financial basis while recognizing the exceptional international tradition and character of the institute, the Naples Zoological Station in 1983 became a state institution under the direct supervision of the Italian Ministry for Public Instruction.

In April, 1897, the 25th anniversary of the foundation of the Zoological Station was celebrated in a very official and festive manner (not without political reasons on Anton Dohrn's part). At that time, 36 tables (2 American) had been rented and more than 900

scientists already had worked there. Following the example set by Naples, approximately 15 similar marine biological stations had been founded all over the world. Anton Dohrn had been awarded several honorary degrees and nominated a member of many societies. On this occasion, he was awarded honorary citizenship of Naples. Nearly 2,000 scientists from all parts of the world signed an address to Anton Dohrn, saying:

> *We are incapable of conceiving what the present state of biological sciences would be without the influence of the Zoological Station.*

You may well say, therefore, that Anton Dohrn was a well-known and famous man when, in August of the same year, he decided to take part in the meeting of the British Association for the Advancement of Science in Toronto, Ontario, and that of the American Association in Detroit, Michigan. But behind this official pretext there was the wish to visit old friends and to further the interests of the Zoological Station in the United States in the face of the authority of Alexander Agassiz who, after having rented a table for Harvard University from 1894 through 1896, suddenly cancelled the contract and tried, it seems, to prevent American participation at Naples in a seemingly underhanded way. Anton Dohrn arrived in New York on 7 August 1897 and proceeded to Woods Hole two days later. He wrote the following letter to his secretary, on 11 August, from Woods Hole.

Dear Linden,

There is little time, so just some cursory notes. Everything seems to be going well. You will find details later in the diary. Last night I had to give a lecture to ladies and gentlemen; the lecture room has never been that crowded, and my old confidence carried me along again so that I had quite a success, which, as Whitman tells me, will be as important for Woods Holl as it will be for Naples. He is prepared to take care of three tables,—Ida Hyde's table should be safe, especially now where all those ladies went out of their minds flirting with me. I don't know how many dozens wanted to be introduced. I would much rather stay here than go to Detroit. There are only second-class biologists there, and it is so charming here. But out of politeness and politics I have to be in Detroit at least for a day. Yesterday carriage/steam launch/excursion, and today Mr. Forbes, one of the American nabobs and friend of Alex. Agassiz, put his steam yacht at my disposal, the same one on which Agassiz went to the West Indies.*

Everything else you will get by separate mail,—this here is just to tell you that I am triumphant yet and will be back in Berlin a winner. It's splendid here at Woods Holl. So, now I have to see one of those hard working ladies.

Adieu. In a hurry, 1,000 greetings!

Your

AD

* This was the correct spelling of Woods Hole in those days—ED.

Christiane Groeben is the Archivist at the Stazione Zoologica, Naples, Italy.

concerns

At-Sea Incineration:

Up In Smoke?

by Michael Stewart Connor

The taint of previous scandals seems to affect all who try to develop the industry and regulations for treatment and destruction of hazardous wastes. Each proposed solution only creates new controversy, augmenting the public's visceral fear of hazardous wastes. A tentative diagnosis suggests that incineration of liquid organic wastes at sea should be immune to this plague of fear. Beyond the Continental shelf, far out of sight of land, incineration ships are reputed to destroy more than 99.99 percent ("four nines" in industry terms) of the chemicals they burn. Yet political opposition is threatening to upset the Environmental Protection Agency (EPA) plan to issue one research and two special permits for the incineration of mixed liquid organic wastes for the next three years in the Gulf of Mexico.

Ocean-based incineration of industrial wastes is conducted aboard ocean-going tankers with high-temperature incinerators capable of maintaining temperatures at the incinerator wall of at least 1,100 degrees Celsius during the burns. Liquid organochlorine wastes from the chemical, plastics, pharmaceutical, and pesticide industries are converted to carbon dioxide, water, and hydrochloric acid.

Presently, there are only two incinerator ships—*Vulcanus I* and *II*—both owned by Chemical Waste Management, the worldwide leader in hazardous-waste disposal. Since 1974, *Vulcanus I* has conducted five burns under EPA research permits, during which 29,100 metric tons of mixed organic wastes from Shell Chemical Company and 5,600 metric tons of polychlorinated biphenyl (PCB) wastes were burned in the western Gulf of Mexico, and 10,400 metric tons of Agent Orange were burned in the Pacific near Johnston Island. Worldwide, the *Vulcanus I* has incinerated almost 400,000 metric tons of hazardous wastes since 1972, mostly at a site in the North Sea about 125 kilometers from the Netherlands. To meet the increasing demand for incineration, the *Vulcanus II* was built in 1982.

The Vulcanus II at work in the North Atlantic Ocean. (Courtesy Steve McAllister/ Greenpeace)

The EPA has designated one incineration site in the western Gulf of Mexico, 315 kilometers southeast of Galveston, Texas, in waters about 1,400 meters deep. The three proposed permits would allow the *Vulcanus I* and *II* to burn 300,000 metric tons of organochlorine wastes at the Gulf site over the next three years. Another site has been proposed about 360 kilometers east of Delaware Bay in waters more than 2,400 meters deep. Both sites cover about 4,900 square kilometers. Final designation of the North Atlantic site is pending, and the EPA is evaluating the need for a potential Pacific Ocean site.

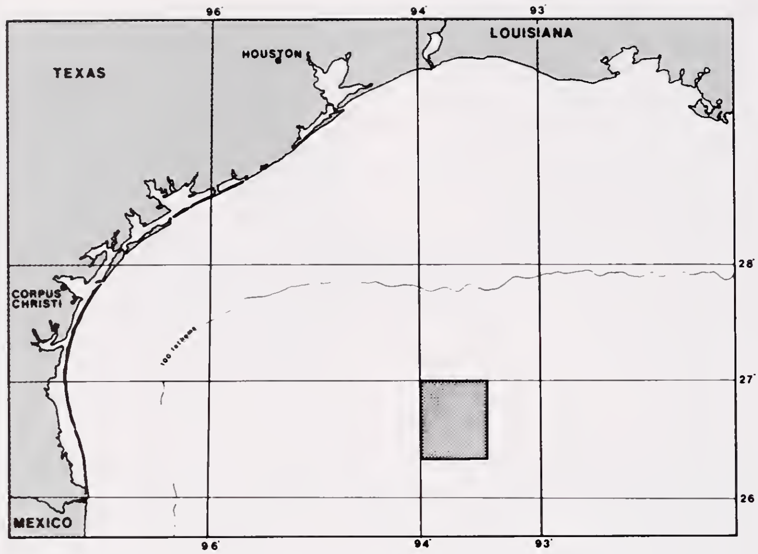
These three incinerator sites would be fully utilized if all the ships currently planned receive permits. To encourage the development of an American incinerator fleet—both the

Vulcanus I and *II* are registered abroad—the Federal Maritime Administration has guaranteed a loan of $55 million to At-Sea Incineration, a subsidiary of Tacoma Boatbuilding Company, for the construction of two ships to be completed in 1984. SeaBurn, Inc., a division of Stolt-Nielsen, a worldwide transporter of bulk chemicals, also notified the EPA of its intent to build an incinerator vessel. Ocean-based incineration entails about half the costs of land-based operations, and the concurrent operation of all these ships could absorb much of the market for liquid incinerable wastes.

Research

The research burns conducted by the *Vulcanus I* and a recent North Sea burn by the *Vulcanus II* were monitored by the EPA. Sampling has included monitoring of stack emissions and air and water quality downwind of the ship. Stack samples usually contain no measurable levels of the organic wastes being combusted, evidence of a destruction efficiency greater than 99.99 percent. Environmental samples were tested and for PCBs show that these compounds also are below detection limits. Fish caged in waters where the incinerator plume touches the surface have been analyzed for PCBs and adenylate-energy-charge ratio, a metabolic indicator of health. Again, no PCB accumulation above background levels was found. Changes in the adenylate-energy-charge ratio were ascribed to stress during shipboard handling.

These research results have been used to justify the safety of at-sea incineration, but the sufficiency of the research program has been criticized. For instance, the EPA was unable to measure PCBs in the ambient air and waters of the Gulf of Mexico, yet these compounds are routinely measured there by other scientists. The absence of PCBs in stack samples could be a result of poor stack-sampling procedures or of conversion of PCBs to other organic



Controversial at-sea incineration site proposed for the Gulf Of Mexico.

compounds. In fact, the EPA stack sampling has been plagued by plugging, corrosion, loss of impinger solution, and poor recoveries. Often, single-point samples have been extrapolated to represent the entire stack plane.

Ideally, instead of searching for the presence of a very small amount of PCB in the stack effluent, the mass of chlorine contained in the wastes to be burned should be balanced against the amount of chlorine in the hydrochloric acid in the stack exhaust. Only then could it be established that combustion had been complete and that no recombination of organic compounds into other hazardous products had occurred. Such a mass balance to 99.99 percent accuracy would be practically impossible, though, given the large temporal variations in the feed and emission rates.

Land versus Sea

These attacks on the EPA monitoring program are reinforced by contentions that the technology utilized in shipboard incineration is far inferior to that used in land technology. Several characteristics make shipboard incineration less efficient than land-based burning: short residence time of the wastes in the flame (one second compared to four seconds used on land); lack of a secondary combustion chamber; and, absence of scrubbers to remove fine particles onto which toxic recombined organic compounds can adsorb. Spokesmen for land-based incineration claim their plants operate at destruction efficiencies greater than 99.999999 percent ("eight nines"), several orders of magnitude better than sea-based incinerators.

To anyone who has spent any time at sea, it is obvious that ship incinerators can not operate as efficiently as their land counterparts. But their emissions may present minimal risks to public health since ocean-based incineration is conducted more than 200 kilometers from the nearest population centers. Ocean-based incineration is superior in some other ways, too. For example, when on-land scrubbers malfunction and increase the amount of toxic products released to the air, local populations are endangered. Even normal operation generates large volumes of scrubber sludges, which must be deposited in landfills.

Besides the differences in stack emissions, land-based incineration is thought to be superior in cases of spills or accidents during the handling of waste and transport to the incinerator site. Judging from the experience of the oil industry, recovery of spilled wastes after a major accident would be quite inefficient at sea. Assessing the significance of such losses involves two determinations: the probability of a ship accident and the potential damage.

Among the approximately 34,000 merchant ships in the world's fleet, there are between 200 and 300 accidents every year. Performance of United States flag ships is slightly better, but there is still about one accident per 1,000 port calls. Clearly, these probabilities could be improved by Coast Guard escort and safety procedures that isolate the incinerator ships from other port traffic. Besides ship collisions and groundings, though, there is a need to assess spills during daily operations caused by equipment failure and explosions resulting from the mixing of incompatible wastes. Losses through small and large spills could be substantial. In the transport of oil, for example, operational losses approach 0.1 percent of the total amount of oil shipped.

The sinking of a ship that contained more than 1,000 metric tons of PCBs would certainly have serious long-term impacts on a region's fisheries. The resulting PCB input would be about 10 times greater than the estimated loadings to the upper Hudson River or New Bedford inner harbor, thought to be the nation's two most severely contaminated aquatic regions. The loss of an entire ship would release into the coastal environment more than 500 times the annual total PCBs released into the New York Bight or the Southern California Bight via disposal of sewage wastes.

The risks associated with storms at sea are unclear, though substantial wave vibrations can induce ship rolling that interrupts pumping of the waste. More consequential, it seems, is the difficulty that would be encountered if a waste-loaded vessel was prevented from leaving harbor by a hurricane or

other conditions. The incinerator ships presently in use can dispose of their load only via incineration.

The risks of transporting hazardous wastes for incineration presents a paradox. Many of these same compounds also are transported at sea in their pure forms as chemical products. For instance, 391 million tons of "hazardous chemical materials" are transported through the Gulf of Mexico each year. On the other hand, PCBs are no longer manufactured in the United States because their chemical properties present special hazards to aquatic systems. In addition, there may be no better alternative to the transport of chemical products by sea while land-based incineration may be a less risky alternative.

Regulations

In part, the EPA's problems with ocean incineration are self-inflicted. Since promulgating general ocean-dumping regulations in 1977, the EPA has yet to formally propose and promulgate specific ocean-incineration criteria as rules. Rather, it has issued permits on an *ad hoc* basis, using a pastiche of criteria from the London Dumping Convention, the Ocean Dumping Act, TSCA, and RCRA. As a result, the states of Texas, Louisiana, and the several regional and national groups have filed a lawsuit challenging the EPA's improper adoption of *de facto* rules. At recent oversight hearings, several members of the House Merchant Marine and Fisheries Committee also demanded that the EPA issue ocean-incineration rules before granting any more permits.

Some of the difficult issues surrounding ocean incineration would be best resolved by a formal issuance of rules. For instance, how can the EPA equitably treat land- and ocean-based incineration? Must at-sea incineration be safer than on-land incineration, or simply designated as one of several acceptable techniques? Is 99.99 percent destruction efficiency sufficient, or should the standard be raised as the technology is improved? As newer incinerator ships come on line, should use of the older *Vulcanus I* be discontinued? Who is responsible for the financing and administration of regular environmental monitoring programs? Should Coast Guard escorts be a standard part of incineration cruises, and who will finance them? These and other questions require policy decisions that the EPA could best standardize with formal rulemaking.

The technology of ocean-based incineration is in a period of rapid development. The ships under construction by At-Sea Incineration are of a design that provides far more control than existing ships and incorporate a number of sophisticated safety features, including state-of-the-art navigation, communication, and collision-avoidance systems. SeaBurn's proposed ships will carry 144 5,000-gallon stainless-steel tank containers sealed at waste-disposal sites to minimize the danger of spills during handling and loading in port. By including flotation on the containers, SeaBurn might incorporate system design to provide for the recovery of wastes in the event of an accident. SeaBurn also plans to reduce stack emissions with seawater scrubbers.

Future Prospects

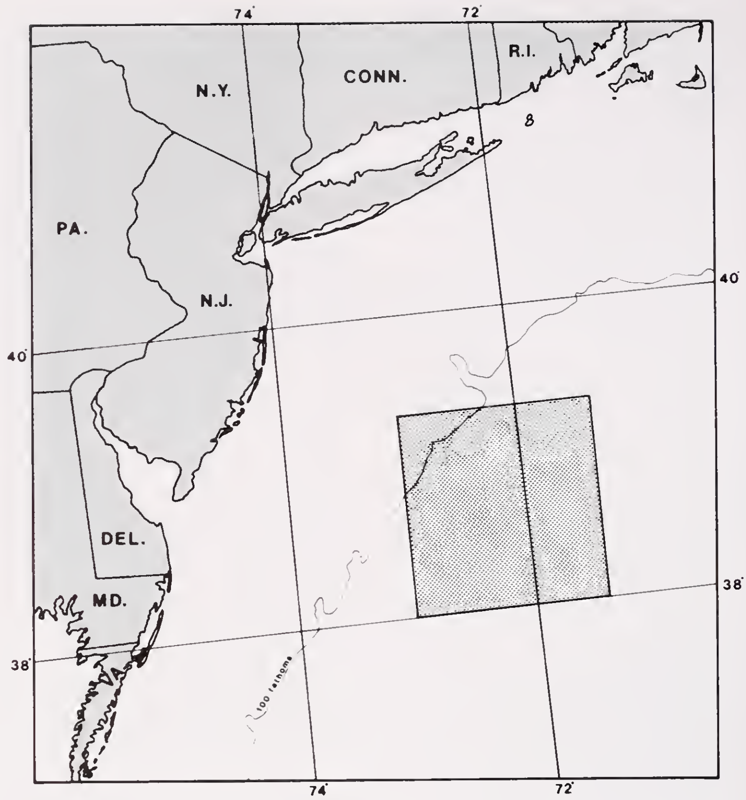
Given the rapid pace of technology development, the EPA may be able to assuage the public fears and criticisms of new regulations by better addressing issues of siting, equity with land-based incinerators, and appropriate use of the marine environment's assimilative capacity. The EPA's recently approved regulation requiring an agency monitor to ride with each ship and observe the incineration process will help assure that permit criteria are enforced. For example, stipulation of the environmental conditions that mandate interruption of the burn cycle (typically 10 24-hour days

of incinerating) can be specified.

Initially, industry perceived that incineration at sea posed less severe siting problems than does on-land incineration. However, the proposed Gulf of Mexico permits have generated tremendous public opposition at both Mobile, Alabama, the port of transfer, and the Texas coastal communities downwind of the site. Community fears, which the industry feels are excessive, are common among all hazardous-waste issues. These concerns are even more important to Texas coastal communities, whose major tourism and fishing industries depend on positive public perceptions.

The Audubon and Cousteau societies and Greenpeace oppose the project. The significant exception to this organizational opposition is the National Wildlife Federation, which supports at-sea incineration as an alternative to land-based disposal. However, the local Texas chapter of the Federation has broken ranks with the national organization over this issue, and National Wildlife has voiced concern about the proposed Gulf site, where onshore winds prevail. While industry may feel justifiably that incineration in the ocean can be conducted safely, the EPA may be able to relieve some of the public's concerns by increasing the margin of safety by relocating the sites even further from land, requiring Coast Guard escorts of incinerator ships, and requiring technology that minimizes the loss of waste during spills.

Another major opponent of shipboard incineration has been the land-based incineration industry. The industry's complaint is that there is no need to permit incineration at sea since the land-based industry is operating 30 to 50 percent below capacity. Indeed, the loan guarantee to At-Sea Incineration by the Maritime Administration seems inequitable in the context of the federal government's overall hazardous-waste-management strategy. Permit approval also places the EPA in the awkward position of being a promoter of at-sea incineration versus those methods not yet fully commercialized. To ensure that ocean-based incinerators are perceived to be fairly paying their way in the future, the EPA should require them to completely fund Coast Guard expenses for providing ship escorts and clean-up response. The land-based incineration industry also argues that incineration at sea fails to recycle the waste heat generated during burning, heat that is used on land to incinerate hard-to-burn hazardous solids, sludges, and tars. Presumably, though, this energy subsidy will be reflected in the economics of land-based incineration.



Proposed at-sea incineration site off the coast of the northeastern United States.

One environmental subsidy not represented economically is the use of the ocean to buffer the hydrochloric acid produced when organic compounds are incinerated and to dilute the undestroyed wastes. The assimilative capacity of the incinerator sites should be determined by the EPA and regulations issued to ensure that this capacity is not exceeded. The ocean-based incineration industry should provide for their monitoring of air, water, and biota potentially affected by the operations. This information also would allow the coastal fishery and tourist industries to document the safety of their products.

These modifications will maximize public acceptance of incineration at sea. Nonetheless, the final decision—whether or not to sanction at-sea incineration—almost surely will be made in the courts. The ocean-incineration industry has too much momentum for the EPA not to issue permits in the coming year, and the opposition is too well organized to allow unchallenged issuance of permits.

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Letters

To the Editor:

During the week of 20–24 February, 1984, the Contracting Parties to the London Dumping Convention (LDC) will be holding their 8th Consultative Meeting in London. I will be attending as Greenpeace International's counsel.

Several important matters concerning ocean disposal of radioactive wastes will be addressed at the meeting. First, there is the issue of the legality of subseabed burial of high-level radioactive wastes under the London Dumping Convention. This past December, the International Maritime Organization (IMO) convened a Legal Experts meeting to consider the legality question. The views of those governments and observers attending that meeting were divided. The five Nordic nations, plus Canada, Ireland, Spain, and Nauru took the position that seabed emplacement is covered by the Convention and therefore prohibited since high-level wastes are included in the Annex I list of substances that can not be dumped. Britain, the United States, and France expressed the view that the Convention, as written, does not cover (or prohibit) such activities, though they agreed that seabed emplacement should be regulated under the LDC if the concept proves to be feasible. The Contracting Parties at the 8th Meeting will address this issue. There will be an effort to reach a consensus position on the legality question, but that may not be possible.

Second, the Contracting Parties have adopted a two-year moratorium resolution concerning low-level radioactive waste dumping. As a complement to that resolution, the Parties agreed to review the risks associated with such disposal. A mechanism was established, in skeletal form, that would result in the gathering of evidence, the convening of an intersessional meeting in 1984, and the reporting of that meeting's findings and recommendations to the 9th Consultative Meeting in 1985. The 8th Consultative Meeting will need to decide the terms of reference for the intersessional meeting, including consideration of such matters as: will the meeting be open to any experts ... will it be a working group (U.S. proposal) ... or a jury/tribunal of selected experts (Canadian proposal), what questions/issues will they seek to resolve (a U.S. proposal has suggested 15 to 20 questions that would provide such a focus), what will the relationship be between the intersessional meeting and the 9th Meeting, as far as the weight to be given to its findings, and where lies the burden of proof, i.e., will the opponents of such dumping need to prove that it is harmful, or will the proponents need to prove that it is safe. These are the kinds of issues that are likely to be addressed in the terms of reference discussion.

Third, the International Atomic Energy Agency (IAEA) will report on the status of its ongoing review of the definition of high-level wastes, standards for disposal of low-level wastes (e.g., release-rate concepts), a definition of *de minimus* quantities of radioactive wastes, etc. The IAEA sponsored a meeting on this subject in Vienna in late November, 1983, and a major meeting is scheduled tentatively for the fall of 1984 to further discuss those matters.

There are other matters that will be addressed at the meeting. At the 6th Consultative Meeting (1981) the Parties agreed to prepare a report on "The Long-Range Strategies and Objectives of the LDC to the Year 2000." Several drafts of that report have been written, and it is quite likely that the report will be approved at the 8th Meeting.

I think the readers of *Oceanus* would be interested in the outcome of this meeting.

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Washington, D.C.

EDITOR'S NOTE: Mr. Curtis' report on the LDC meeting will appear as a Concerns piece in the Summer issue.

To the Editor:

Robert E. Bowen, in his article "Reagan Stand on LOS Treaty Could Prove Costly" (Vol. 26, No. 3, Fall 1983), states that the United States will experience difficulties in marine-related activities if we do not sign this treaty. Dr. Bowen, however, does not discuss the treaty provisions that concern marine science. Considerable evidence, including close reading of the proposed treaty itself, exists to indicate that U.S. interests, and especially those of marine scientists, would be harmed by U.S. participation in this treaty.

The provisions in this treaty that concern marine research should be of particular interest to readers of *Oceanus*. David A. Ross and John A. Knauss, writing in *Science* (Vol. 217: 10 September 1982), state that "if the treaty enters into force, the marine science articles will restrict many activities of U.S. marine scientists..." Nearly 40 percent of the oceans will be placed under the jurisdiction of bureaucrats, most of whom, we can assume, will know little if anything about the concerns of marine scientists. The treaty contains strict provisions governing the conduct of marine research. A coastal state may deny permission for research in a zone extending 200 miles from its coasts. There are no provisions for appeal of a state's decision. Six months prior to commencement of the proposed research, scientists must submit to the involved states a

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complete plan, including descriptions of scientific equipment, vessels, personnel, nature and objectives, methods and means, etc. Researchers will be required to train on board ship any persons designated by the host country. Researchers will not only be required to provide to the host country copies of all data and conclusions, but also must make themselves available to "provide assistance in data assessment or interpretation." The host may suspend permission for a research project at any time, if it feels that its requirements are not being met.

In addition to all of the aforementioned barriers to marine research, a host state may forbid the publication of results of research if natural resources are discussed. Thus, a scientist could spend years, money, and ship time attempting to comply with all of the regulations, only to find that he would not be permitted to publish his research. In conclusion, I am amazed that Mr. Bowen, who, being associated with WHOI, might be thought to have some sensitivity to the requirements of marine research, would feel that President Reagan is wrong in opposing the LOS treaty.

Dianne E. Stewart
Palo Alto, California

While I share many of Ms. Stewart's concerns over the marine science provisions of the U.N. Convention on the Law of the Sea, I do not agree that a U.S. refusal to sign the convention will alter the establishment of marine scientific consent regimes.

The International Court of Justice, as part of its decision on the Libyan/Tunisian continental shelf, has stated that the concept of an exclusive economic zone (EEZ) is, in fact, established state practice and is part of customary international law. While the court did not attempt to define precisely the nature of state jurisdiction within the zone, the dominant trend is clearly to include such consent regimes in defining EEZ jurisdiction. Although the United States has not done so, President Reagan did acknowledge the right of other countries to regulate marine science within 200 miles of their respective coasts. The problem then becomes the degree to which other countries will attempt to regulate the activity—the convention is reasonably ambiguous in its provisions relating to marine scientific research.

My article argued that one of the responses to the U.S. refusal to sign the convention could be that the regulation of marine science will be used by certain states to retaliate against the U.S. position. Were that to be the case, the loss would be substantial for U.S. marine research. As my article stated, these costs need to be systematically incorporated into the evaluation of a U.S. decision not to sign the treaty.

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Marine Policy and
Ocean Management Program,
Woods Hole Oceanographic
Institution

book reviews

Black Apollo of Science: The Life of Ernest Everett Just by Kenneth R. Manning. 1983. Oxford University Press, N.Y./Oxford, England. $29.95. 397 pp.

Black Apollo of Science by Kenneth R. Manning is a powerful and moving scholarly work. Dr. Manning has reconstructed the tragic life history of Ernest Everett Just, interweaving this black American's personal history with discussions of cultural, historical, political and scientific trends that molded Just's character and personality and inexorably impeded his career as a scientist.

This is not, however, a story of frustrated brilliance (even genius, according to Frank R. Lillie, who perhaps knew Just and his work better than anyone), for Just did go on to become one of the foremost workers in his field, recognized as such in the United States and especially in Europe. What is particularly poignant about Just's struggle is that he fared no better—indeed often worse—among his black colleagues than among his white associates. Both, by and large, "condemned" him to remain in what was then an academically inferior university environment, smothered by faculty politics, and overworked with routine teaching responsibilities, in the name of working for the advancement of his "race." Just, Manning makes clear, had sincere concern for black problems and their alleviation. His primary life goals, however, were those of any true scholar and went beyond racial or national boundaries. He wanted his work to advance the limits of man's knowledge about the natural world.

The extent to which Just was able to achieve this goal is demonstrated in part by his numerous technical publications and his significant theoretical book, *The Biology of the Cell Surface* (1939). Manning summarizes some of these contributions and presents them on their own scientific merit for that period, quite apart from (and appropriately so) the personal difficulties under which Just was laboring both as a black and as a member of the larger intellectual community, which is not notable for any special immunity to common human frailties.

Manning's book is based upon a foundation of exhaustive research of original source materials, all of which are made known to the reader in the extensive citation notes. No less impressive are the sensitive, intuitive insights that Manning brings to bear in portraying Just's reactions to people and events in the America and western Europe of his time (1883–1941).

This reviewer has known many of the scientists documented by Manning to have had an

impact (either positive or negative) on Just's career. My impression is that Manning gives both supporters and detractors honest and fair treatment. In any case, his literature citations and direct quotations from records leave no opportunity to question the accuracy of the author's data. The recurrent theme of Just's complex interaction with his mentor, later colleague and life-long supportive older friend, Frank R. Lillie, is handled with sensitivity and objectivity by Dr. Manning.

Sections of the book dealing with the qualities and objectives of various schools, colleges, universities, research stations, and foundations in the United States and Europe are valuable historical contributions of great interest.

Whether Manning is discussing philosophy, history, or experimental embryology (Just's specific field of research), the writing style is clear and the story flows along in a spellbinding fashion.

Lucena Barth,
Reprinted from *The Collecting Net*,
Marine Biological Laboratory,
Woods Hole, Massachusetts

***The Times Atlas of the Oceans,* Alistair Couper, ed. 1983. Times Books of London/Van Nostrand Reinhold Co., N.Y. $90.50. 272 pp.**

The Times Atlas of the Oceans is designed primarily for the marine specialist, particularly the policy maker or researcher interested in any aspect of ocean resources. This statement does not imply that the book's focus is narrow. Not at all. This book explains, in a straightforward manner, the physical and biological interactions of living resources as well as their international character. At the same time it amply covers the nonliving resources of the oceans. Thus, the nonspecialist will find much of value here.

The atlas covers the following major topics: the geography of the oceans and seas, the ocean basins, the ocean-atmosphere system, the oceans and life, living resources, the fisheries, oil and gas, mineral and energy potentials, ports of the world, ships and cargoes, shipping routes, the hazardous sea, the health of the oceans, the strategic use of the oceans, marine archaeology and underwater technology, management of the oceans, and the law of the sea. The individual sections are complemented by more than 550 maps, charts, diagrams, and photographs, many in full color. Cross-references are provided for all subjects.

Yachtsmen should find the atlas useful, too. There is considerable information on ocean races, navigational aids, and high-risk weather environments. Those engaged in ocean-management activities will find it valuable for its listings of conservation programs, maritime jurisdictional zones, and the problems of multiple sea use.

The editor of the atlas, Professor Alastair Dougal Couper, is head of the Department of Maritime Studies at the University of Wales Institute of Science and Technology, England. The contributors include many distinguished cartographers, geographers, geologists, Master Mariners, mechanical engineers, and meteorologists, both in England and abroad. In short, this team has attempted to give those with a need for up-to-date information on the latest ocean endeavors—from marine archaeology to the causes of ship collisions and the use of satellites—a comprehensive, one-stop reference source.

This writer considers it a good working tool for anyone needing basic, reliable information about the present state of the oceans, including lay researchers, students, and those working in the marine community. The price, unfortunately, may relegate it mostly to the shelves of libraries as a reference work.

Paul R. Ryan

***Deep-Sea Biology,* Gilbert T. Rowe, ed. 1983. Volume 8 in the series The Sea: Ideas and Observations on Progress in the Study of the Seas. John Wiley & Sons, New York, N.Y. 560 pp. $69.95.**

Major methodological and conceptual progress has been made in the study of the deep sea during the last 25 years, and particularly during the last 15 years. *Deep-sea Biology* presents an up-to-date and much wanted review of aspects of animal life in the deep darkness of the oceans.

The seven previous volumes in the series "The Sea" covered topics in physical, chemical, and geological oceanography. Volume 8 is the first volume to deal exclusively with the biology of the deep oceans.

Nineteen recognized authorities (mostly North Americans) summarize the subject in 12 scientific papers of varying length (19 to 79 pages). The volume starts appropriately with a historic review of deep-sea research. E. L. Mills concludes that the growth of oceanography has been strongly influenced by politics, economics, and technology rather than strict scientific (internal) causes. G. T. Rowe and M. Sibuet, in Chapter 2, describe equipment that has been instrumental in the progress of deep-sea research.

There are four chapters on the general ecology of specific compartments of the deep sea: G. T. Rowe deals with the macrobenthos, M. E. Vinogradov and V. B. Tseitlin discuss the pelagic domain, H. Thiel evaluates the ecological importance of meio- and nanobenthos, and H. W. Jannasch and C. O. Wirsen present the ecology of the microbiota. A general trend in the deep sea is the exponential decrease of biomass with depth. Carbon is channelled to great depths by migrating pelagic organisms and by particles settling in the sediments. Bacteria show a complex metabolic sensitivity to varying amounts of pressure.

The last six chapters include a variety of topics. In Chapter 7, C. N. Somero, J. F. Siebenaller, and P. W. Hochachka review the biochemical and physiological adaptations of deep-sea organisms (particularly fishes). The low temperatures and extremely high pressures found in the deep sea reduce the efficiency of enzyme systems, the protein content, and the skeletal components of organisms. Thereafter, K. L. Smith and K. R. Hinga describe the methodology of measuring sediment community respiration and the characteristics of selected oceanic regions. Zonation or the change with depth of the fauna is discussed in an analytical paper by R. S. Carney, R. L. Haedrich, and G. T. Rowe. P. A. Jumars and J. E. Eckman summarize less than 10 years research on the spatial structure of benthic communities, where aggregation is best understood in megafaunal communities. Chapter 11 provides a review of the many hypotheses explaining the high species diversity in the deep sea. The analysis by M. A. Rex clearly shows a maximal diversity at 2,000 to 3,000 meters. R. A. Campbell concludes the volume with a long chapter on parasitism, showing that a variety of protozoans, helminths, and copepods depend on deep-sea invertebrates and vertebrates to complete their life cycles.

I read the book with much interest; several chapters are plainly excellent. They will prove to be particularly useful as references for deep-sea biologists, but also for marine biologists and oceanographers in general. Some papers will appeal to a broader scientific community. Very few articles reflect research completed after 1980, which explains the very concise coverage of hydrothermal-vent biology.

Graphs and pictures illustrate the articles appropriately, but I looked in vain for articles on population genetics, benthic boundary layer-organizer interactions, and evolutionary deep-sea biology. The papers on instrumentation and microbiology are somewhat thin, but Chapters 1, 4, 7, and 10 are marvelous. Several chapters in *The Environment of the Deep-sea* by W. G. Ernst and J. C. Morin (eds.) complement the Rowe publication (chapters 8 and 9 on bacteria, 10 on deep-sea community structure, 13 on nutrition, and 14 on the paleontological history of the deep-sea). Together, these books provide a balanced view of the state of the art in deep-sea biology.

The main contribution of *Deep-Sea Biology* is its summary of past research in a series of stimulating papers. A few authors also attempt to present a general theoretical framework. It provides a solid foundation for students of deep-sea life.

**Filip Volckaert,
Department of Oceanography,
Dalhousie University,
Halifax, Nova Scotia**

Books Received

Aquaculture

The Salmon Handbook: The Life and Cultivation of Fishes of the Salmon Family **by Stephen Drummond Sedgwick; illustrated by Robin Ade. 1982. Andre Deutsch Ltd.; Distributed by Scholium International, Inc., Great Neck, N.Y. 247 pp. + xvi. $26.50.**

Atlantic salmon, Pacific salmon, trouts and chars: these fish make up the most valuable group of the world's fish species. Many of them are anadromous, and they have fascinated people for centuries with their ability to return from the sea to the rivers in which they were spawned. Many human communities have depended for sustenance on migratory salmon and char. This book includes general information on the biology of members of the salmon family and covers behavior, ecology, and cultivation: feeding, diseases and treatment, farming techniques, and marketing.

Biology

Coevolution, **Douglas J. Futuyma and Montgomery Slatkin, eds. 1983. Sinauer Associates, Sunderland, Mass. 555 pp. + x. $46.50 (hardcover); $24.95 (paperback).**

The study of coevolution, for the purposes of this book, has two facets: analysis of reciprocal genetic changes that might be expected to occur in two or more ecologically interacting species, and analysis of whether the expected changes are actually realized. Obviously, there are many applications of such studies—plants and herbivores, pollinators and seed dispersers, and so forth. Twenty-three systematists, paleontologists, ecologists, and genetisists contributed the 18 chapters of this volume; they take different approaches to coevolution and often reach different conclusions. The editors briefly review these ideas in the epilogue, in an attempt to provide "a step toward synthesis rather than the synthesis we may hope someday will emerge."

Breeding Birds of Long Point, Lake Erie **by Jon D. McCracken, Michael S. W. Bradstreet and Geoffrey L. Holroyd. 1981. Canadian Wildlife Service Report Series Number 44, Minister of Supply and Services, Ottawa, Canada. 74 pp. $14.10 (Canadian).**

This book is a detailed study of one of the best examples of dune and marsh ecosystems on the Great Lakes. Beginning with a consideration of the physical setting and climate of Long Point, the authors describe the vegetation and avian communities. Analysis of census data from each stage of dune and marsh succession shows how bird-species diversity is related to vegetation heterogeneity. An annotated list of the breeding birds follows. Of interest to ornithologists and ecologists alike, the book is available in French and English editions.

Green Planet: The Story of Plant Life on Earth, **David M. Moore, ed. 1982. Cambridge University Press, New York, N.Y. 288 pp. $27.50.**

An encyclopedia of plant ecology and geography, illustrated in color with 300 photographs and 100 explanatory drawings. There are 7 chapters: 2 on the origins of plant ecology and geography as disciplines and some of the techniques used by practitioners in these fields; 4 surveying the plants of the world; and one on man's dependence on Earth's vegetation and its components, reviewing the impact of modern humanity on plant life. Also included are biographies of people important in the history of plant ecology and geography.

Physiology and Biology of Horseshoe Crabs: Studies on Normal and Environmentally Stressed Animals, **Joseph Bonaventura, Celia Bonaventura, and Shirley Tesh, eds. 1982. Alan R. Liss, Inc., New York, N.Y. 316 pp. + xvii. $48.00.**

The horseshoe crab, *Limulus polyphemus*, is interesting to scientists both for its evolutionary significance and for its use in biomedical research. This book contains 18 essays covering a wide range of topics about the horseshoe crab. Beginning with a pictorial review of *Limulus*'s natural history, the book discusses biochemistry, developmental biology, and physiology. Ending the text are essays on man as an environmental threat to *Limulus* and the roles and responsibilities of biologists in today's society.

The Larvae of Indo-Pacific Coral Reef Fishes **by J. M. Leis and D. S. Rennis. 1984. University of Hawaii Press, Honolulu, Hawaii, 269 pp. $25.00.**

This book describes the larval stages of 49 families of coral reef fishes inhabiting the region from Hawaii and northern Australia to the Red Sea

and southeast Africa. These larvae can be extremely difficult to identify, a task this book helps alleviate. After the introduction and material on terminology and collecting and identification methods, and an explanation of the format and how to use the book, the fish are covered by order (Myctophiformes, Ophidiiformes, Atheriniformes, Beryciformes, Gasterosteiformes, Scorpaeniformes, Perciformes, Gobiesociformes, Pleuronectiformes, Tetradontiformes). Within each order the fishes are discussed by family, with information on adults, spawning mode, development and hatching, and larvae, and line drawings illustrating the sequence of development typical for the family.

***Marine Invertebrates of Southern Australia, Part I.* S. A. Shepherd and I. M. Thomas, eds. 1982. Government Printing Division, Department of Services and Supply, Director and Government Printer, Netley, South Australia. 491 pp. $17.00 (Australian).**

This book is a descriptive guide to the species common to the coast of southern Australia. The coverage varies proportionately with zoological understanding of each group. The first two chapters cover the marine environment and food webs in general; following are 10 chapters on the different phyla, which incorporate keys and species descriptions and notes on distribution, ecology, and life histories. There are two sections of underwater color photographs.

***Seals of the World* by Judith E. King, 2nd edition. 1983. British Museum of Natural History; Comstock Publishing Associates, Cornell University Press, Ithaca, N.Y. 240 pp. $24.50.**

In two sections, this book provides a comprehensive account of what is known about pinnepeds. The first section begins with classification, gives an account of each living species (distribution, life history, food, habits, and commercial exploitation), and has a chapter on fossils, relationships, and chromosomes. Section Two is on biology, with chapters on flippers and locomotion; skin, fur and temperature regulation; and the other biological systems of seals. Also covered are parasites, pathology, and pollution problems. A third section, Appendices, supplies information on scientific names, references, and suggestions for further reading.

Environment/Ecology

***Remote Assessment of Ocean Color for Interpretation of Satellite Visible Imagery: A Review* by Howard R. Gordon and Andre Y. Morel. 1983. Volume 4 of Lecture Notes on Coastal and Estuarine Studies, Springer-Verlag, New York, N.Y. 114 pp. $20.00.**

The purpose of this book is to reassess ocean-water-color remote sensing, including experiences with Coastal Zone Color Scanner (CZCS) imagery. The CZCS is used to observe the variations in the ocean's color produced by pigments in phytoplankton. The text begins by outlining the physics of water-color remote sensing and the fundamentals of atmospheric corrections; it critiques the present state of constituent retrieval and atmospheric correction algorithms and presents samples of imagery for comparison with experiments. Two appendices describe the CZCS and summarize the developments in color remote sensing that took place during the production of this report.

***From Year to Year: Interannual Variability of the Environment and Fisheries of the Gulf of Alaska and the Eastern Bering Sea,* Warren S. Wooster, ed. 1983. Washington Sea Grant, University of Washington, Seattle, Wash. 208 pp. + vii. $8.00.**

The results of a workshop held at Lake Wilderness, Washington, in May, 1983, to review existing knowledge on ocean and fish variability and to develop a strategy for investigating such interactions. This project grew out of the "Ocean Environment and Fisheries Resources" program at the University of Washington. Nine papers, each followed by commentary, discuss the determinants of stock abundance, abundance trends of Pacific herring, abiotic environmental variations, changes in recruitment of gadoid fishes, and more. A synthesis of future research strategies was identified by the workshop members and recommended considering the needs of researchers in this field and the capabilities of the institutions involved in such research.

***Marine Ecosystem Modeling: Proceedings from a Workshop Held April 6–8, 1982,* K. W. Turgeon, ed. 1983. National Environmental Satellite, Data and Information Service (NESDIS), NOAA, U.S. Department of Commerce, Washington, D.C. 274 pp. + xiii. $10.00.**

The objective of the workshop was to discuss and assess the role of ecosystem modeling in marine environmental assessment and resource management. Participants were invited from government, academia, research institutions, and private industry. The proceedings include 11 invited papers followed by the reports of 4 working panels. The papers focus on modeling of near-shore ecosystems and assessing the impacts of oil spills on the outer continental shelf. Topics for the working panels were: fisheries management, environmental management, linkage of biological and physical models, and integrating modeling into a socio-economic framework. The invited papers are useful ecosystem case studies; the panel reports provide more general discussion on the use of models.

***Chesapeake Waters: Pollution, Public Health, and Public Opinion, 1607–1972* by John Capper, Garett Power, and Frank R. Shrivers, Jr. 1983. Tidewater Publishers, Centreville, Md. 201 pp. + x. $19.95.**

Though the Chesapeake Bay estuary has been intensively studied by scientists, little has been done toward understanding the Bay's role in politics, culture, and economics. In this book, the authors survey the history of water-quality issues on Chesapeake Bay from 1607 to the 1970s. Public health concerns about the Bay emerged early in the colonial period, and since that time the people of the region have taken great interest in the Bay, reflected in the evolution of their governments' attentions to the area. Illustrated with photographs, maps, and drawings, this book focuses on ideas and attitudes about this special bay, and the institutions developed to deal with water quality and related issues there.

***The Fertile Fjord: Plankton in Puget Sound* by Richard M. Strickland. 1983. Puget Sound Books, Washington Sea Grant, Seattle, Wash. 146 pp. + xv. $8.95.**

A review for those interested in natural history of the plankton of Puget Sound and their relationships

in the pelagic food web there, this book attempts to identify gaps in knowledge and data, and bridge such gaps where possible. Nine chapters introduce readers to plankton biology and study techniques, types of plankton and their ecology in varied environments, zooplankton, the effects of pollution on plankton, red tides, and a discussion of plankton harvesting by man. A glossary and guide to pronunciation are included, with bibliographic notes for each chapter.

***Pollution and the Biological Resources of the Oceans* by S. A. Patin. 1982. Butterworth Scientific, Boston, Mass. 287 pp. + xi. $89.95.**

Translated from Russian, this book presents general results of investigations into marine pollution. It emphasizes the combination of experimental data on the response of aquatic species and populations to perturbing effects with the content and distribution of pollutants in marine ecosystems. The most widely distributed toxicants (metals, petroleum, organochlorine compounds, surfactants and long-lived radionuclides) are examined as ecological factors in marine life. There are 12 chapters on a range of subjects, including trends in research, world ocean-pollution patterns, and global biological consequences of marine pollution. Nine appendices provide data on the effects of specific pollutants on specific organisms.

***The Beaches Are Moving: The Drowning of America's Shoreline* by Wallace Kaufman and Orrin H. Pilkey, Jr. 1983. Part of the series, Living with the Shore. Duke University Press, Durham, N.C. 336 pp. + ix. $9.75.**

The effects of American civilization on our country's beaches have been great: social, political, and economic factors complicate the reality of physical processes along the shoreline. The coast attracts millions of visitors and supports a heavy human population; yet, the effects of humans, through development and shoreline "defense projects," have been to greatly alter or destroy coastal areas and barrier islands. This book addresses these problems, and includes a new epilogue discussing the Barrier Islands Bill, the Coastal Zone Management Act, and the Skidaway statement. It provides information for making wise, environmentally sound decisions about buying or building on a beach and has a guide to national seaside parks where one can see "the most beautiful and most beleaguered beaches on three coasts."

***Estuaries and Enclosed Seas*, Bostwick H. Ketchum, ed. 1983. Part of the series, Ecosystems of the World. Elsevier Scientific Publishing Company, New York, N.Y. 500 pp. + xii. $170.25.**

Estuaries constitute a small but vital part of the marine environment: they provide a home for many species and breeding or nursery grounds for many more, and are migration routes for anadromous fishes. Estuaries are important to human populations, as sources of food, for example. This volume, divided into a section on estuaries and one on enclosed seas, summarizes much accumulated knowledge and is intended as a reference and guide for future studies. The section on estuaries contains seven chapters about the environmental variations of estuaries and the effects of these variations on estuaries' resident flora and fauna, including estuarine characteristics, circulation, responses to estuarine stress, phytoplankton and zooplankton, benthos, and fishes. Section II includes an introduction to enclosed seas, followed by nine chapters on individual enclosed seas of the world: the Mediterranean, the Black Sea, the Red Sea, the Gulf of St. Lawrence, and others.

Engineering

***Resistance and Propulsion of Ships* by Sv. Aa. Harvald. 1983. Wiley-Interscience, John Wiley & Sons, New York, N.Y. 353 pp. + xii. $59.95.**

Some of the problems of resistance and propulsion in ship design are covered in this book, written by a professor of ocean engineering at the University of Denmark. A study of practical and analytical design considerations, this book will be useful to students and engineers with no special training in ocean engineering. All variables and terms are defined. The ten chapters cover mathematical and physical models, ship resistance and its determination, propulsion and the ship-machinery-propellor interaction, prediction of ship's power, model-ship correlation, and examples of prediction of power.

Geology

***Geosynclines: Concept and Place within Plate Tectonics*, F. L. Schwab, ed. 1982. Hutchinson Ross Publishing Company, Stroudsburg, Penn. 411 pp. + xv. $52.00.**

Geosynclinal theory has been used to explain the origins of mountain systems and distributions of thick lithological assemblages of sediment ever since James Hall, in 1859, proposed that a direct causal relationship exists between such mountains and sediments. Since its conception, the theory has been flexible enough to withstand many differences of interpretation and adaptations to new models of Earth, and in the 1960s and 1970s, geosynclinal theory was largely incorporated into plate-tectonic theory. Covering the period from 1859 to 1977, this volume presents 46 papers that trace the development of the geosynclinal concept.

***The Dynamic Earth.* A Scientific American Book. 1983. W. H. Freeman and Company, New York, N.Y. 136 pp. $13.95.**

Originally published as articles in the September, 1983, issue of *Scientific American*, the chapters of this book are written by the scientists respon-

sible for the "revolution" in geology. Two decades ago, recognition of continental drift started this revolution. Now we have a coherent theory of our planet's workings, explained in these chapters on the Earth's core, mantle, oceanic and continental crusts, the ocean, atmosphere, and biosphere. Included at the end of the book are brief biographies of the authors, bibliographies, and an index.

Marine Policy

***Economics of Ocean Resources: A Research Agenda,* Gardner M. Brown, Jr., and James A. Crutchfield eds. 1982. University of Washington Press, Seattle, Wash. 242 pp. $12.00.**

The proceedings of a workshop sponsored by the Office of Ocean Resources Coordination and Assessment (ORCA), held on Orcas Island, Washington. The purpose of the meeting was to create a departure point for research in the development, utilization, and management of ocean resources. The book begins with a general paper on ocean resources, followed by studies of living resources, oil and gas, marine minerals, marine recreation, and marine-environmental management. After each study are discussions of the subject matter.

General

***Marine Technology in the 1990s,* H. Charnock and A. M. Adye, eds. 1982. The Royal Society, London; distributed by Scholium International, Inc., Great Neck, N.Y. 210 pp. + vii. $62.00.**

The papers in this volume, contributions to a meeting of the Royal Society of London, describe important developments in marine technology and assess their potential for exploitation of marine resources and improved observation of the ocean. There are 11 essays on offshore structure and design, the development of a single-well oil-production system, defense applications of marine technology, ships and shipping, techniques in diving and submersibles, deep-ocean drilling, organic resources of the sea, mariculture technologies, ocean mining, energy from the ocean, and "observing the ocean in the 1990s."

***A Field Guide to the Whales, Porpoises and Seals of the Gulf of Maine and Eastern Canada: Cape Cod to Newfoundland* by Steven K. Katona, Valerie Rough, and David T. Richardson; illustrations by John R. Quinn, D. D. Tyler, and Sarah Landry. 1983. Charles Scribner's Sons, New York, N.Y. 25 pp. + xv. $12.95.**

In three parts, plus appendices and bibliography, this book describes in words and pictures 28 species of marines mammals and three "bonuses for whalewatchers"—basking sharks, ocean sunfish, and leatherback turtles. Each description begins with a drawing of a representative member of the species, its common and scientific names and size range; the text includes information on appearance, feeding, mating and reproduction, and other life-history information, as well as notes on where the species may be seen, its commercial and population status, and any outstanding features such as the huge size of the blue whale. The appendices include important prey species of whales, porpoises, and seals, and a list of whale- and seal-watching excursions, each with postal address and short description. The bibliography is conveniently keyed so that one can quickly locate references on particular species of interest.

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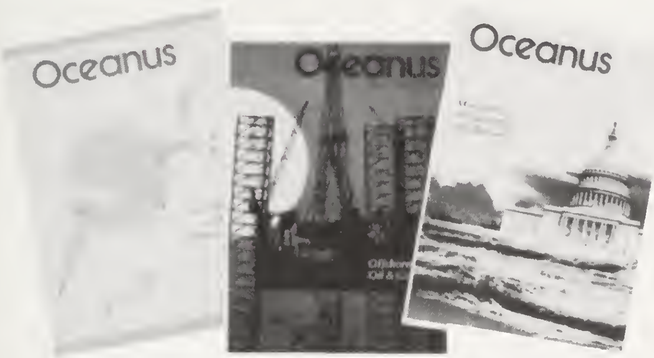

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Issues not listed here, including those published prior to Spring 1977, are out of print. They are available on microfilm through University Microfilm International; 300 North Zeeb Road; Ann Arbor, MI 48106.

- **Oceanography in China,** Vol. 26:4, Winter 1983/84—Comprehensive overview of the history of marine studies in China, including present U.S.-China collaboration, tectonic evolution, aquaculture, pollution studies, seaweed-distribution analysis, the changing role of the Yangtze River, and the administrative structure of oceanographic programs.
- **Offshore Oil & Gas,** Vol. 26:3, Fall 1983—Historical accounts of exploration methods and techniques, highlighting development of seismic theory, deep-sea capability, estimation models, as well as environmental concerns, domestic energy alternatives, and natural petroleum seeps.
- **General Issue,** Vol. 26:2, Summer 1983—Articles cover the effects of carbon dioxide buildup on the oceans, the use of mussels in assessments of chemical pollution, a study of warm-core rings, neurobiological research that relies on marine models, the marginal ice zone experiment, and career opportunities in oceanography. A number of "concerns" pieces on the U.S. Exclusive Economic Zone round out the issue.
- **Seabirds and Shorebirds,** Vol. 26:1, Spring 1983—This issue contains articles on the feeding methods, breeding habits, migration, and conservation of marine birds.
- **Marine Policy for the 1980s and Beyond,** Vol. 25:4, Winter 1982/83—The articles focus on the problems of managing fisheries, the controversy over dumping wastes in the oceans, the lack of coordination in United States Arctic research and development, military-sponsored oceanographic research, the Law of the Sea, and the potential for more international cooperation in oceanographic research. Each author makes recommendations for the future.
- **Deep Ocean Mining,** Vol. 25:3, Fall 1982—Eight articles discuss the science and politics involved in plans to mine the deep ocean floor.
- **General Issue,** Vol. 25:2, Summer 1982—Contains articles on how Reagan Administration policies will affect coastal resource management, a promising new acoustic technique for measuring ocean processes, ocean hot springs research, planning aquaculture projects in the Third World, public response to a plan to bury high-level radioactive waste in the seabed, and a toxic marine organism that could prove useful in medical research.
- **Oceanography from Space,** Vol. 24:3, Fall 1981—Satellites can make important contributions toward our understanding of the sea.
- **General Issue,** Vol. 24:2, Summer 1981—A wide variety of subjects is presented here, including the U.S. oceanographic experience in China, ventilation of aquatic plants, seabirds at sea, the origin of petroleum, the Panamanian sea-level canal, oil and gas exploration in the Gulf of Mexico, and the links between oceanography and prehistoric archaeology.
- **The Coast,** Vol. 23:4, Winter 1980/81—The science and politics of America's 80,000-mile shoreline.
- **Senses of the Sea,** Vol. 23:3, Fall 1980—A look at the complex sensory systems of marine animals.
- **A Decade of Big Ocean Science,** Vol. 23:1, Spring 1980—As it has in other major branches of research, the team approach has become a powerful force in oceanography.
- **Ocean Energy,** Vol. 22:4, Winter 1979/80—How much new energy can the oceans supply as conventional resources diminish?
- **Ocean/Continent Boundaries,** Vol. 22:3, Fall 1979—Continental margins are being studied for oil and gas prospects as well as for plate tectonics data.
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